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Influence of Underwater Sound and Nearshore Vessel Activity on Western Gray Whale Behaviour During the Installation of a Concrete Gravity Base Structure off Sakhalin Island, Summer 2005

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Influences of Underwater Sound and Naeashore Vessel Activity on Western Gray Whale Behaviour during the Installation of a Concrete Gravity Based Structure off Sakhalin Island, Summer 2005

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Influences of Underwater Sound and Nearshore Vessel Activity on Western Gray Whale Behavior during the Installation of a Concrete Gravity Based Structure off Sakhalin Island, Summer 2005

Photo taken from shore at North Station. G. Gailey

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Introduction

This report contains analyses of western gray whale (*Eschrichtius robustus*) behavior off northeast Sakhalin Island, Russia, during 2005 offshore construction activities. Our purpose was to assess and quantify potential impacts on gray whale behavior of underwater sound levels produced by industrial construction activities related to placement of a concrete gravity based structure (CGBS). This assessment was initiated in part because of the proximity of the CGBS location to the primary feeding ground (Piltun feeding area) of western gray whales. The analyses involved relation of movement and respiration ("behavioral") variables to natural and anthropogenic variables using multiple-predictor regression analysis (hereafter, multivariate regression). This approach allows us to evaluate potential behavioral responses of gray whales to underwater industrial sounds emanating from CGBS construction activities as well as nearby research vessel activity after considering and accounting for natural effects, such as environmental, temporal, and spatial effects. A previous report (Gailey *et al.* 2006) examined univariate "broad scale" analysis of behavior related to categorical variables because detailed underwater sound level information was not available at the time. We compare these previous analyses with our current approach. We also compare the current approach to multivariate analyses conducted on data collected in 2001 when geophysical seismic survey activities were present in the same general area for part of the gray whale feeding season (Gailey *et al.* Submitted).

Background and Summary of Previous Studies

The western stock of gray whale is one of the most endangered large baleen whale populations in the world (USFWS 1997, Red Book of the Russian Federation 2000, Hilton-Taylor 2000). An estimated 120 whales feed off the northeastern coast of Sakhalin Island in summer-fall, and are presumed to over-winter in the South China Sea (Cooke *et al.* 2006, IISG Report 2006, Jones and Swartz 2002).

The feeding grounds of western gray whales are in the vicinity of existing and planned oil and gas developments being conducted by the operators of the Sakhalin-1[Exxon Neftegas Limited (ENL)] and Sakhalin II [Sakhalin Energy Investment Company (SEIC)] projects. Sakhalin-1 and Sakhalin II have sponsored several monitoring programs to understand natural variation and potential impacts that these activities may have on western gray whale behavior, movement, abundance, distribution, and population trends. The current management approach involves continual monitoring of western gray whales during their summer and fall foraging period to provide additional understanding of the population, and active mitigation of potential industrial effects on the population.

While western gray whales face several threats during their annual north-south migration along the west coast of Asia, a concern during their feeding season off northeast Sakhalin Island is potential effect from exposure to underwater sound produced by oil and gas development operations (vessel traffic, drilling, dredging, construction, etc.). Anthropogenic sound can influence the behavior of a number of baleen whale species (see Richardson *et al.* (1995) for a summary) and monitoring changes in behavior can be useful as leading indicators that may reveal effects anthropogenic activity may have on the whales. Tyack and Clark (1998) found that migrating eastern gray whales avoided a low frequency acoustic sound source when it was located directly in their migratory path. However, when the same sound source was placed offshore, no apparent avoidance behavior was observed. An experimental exposure of eastern gray whales on feeding grounds in the Bering Sea to playback of continuous sounds revealed that whales changed swim direction at received levels (broadband SPL) ranging from 110 dB re µPa (10% of population) to 120 dB re µPa (50%) and 130 dB re µPa (90%). Malme *et al.* (1986) found that ~10% of eastern gray whales stopped feeding and moved away from transient (seismic) sounds when received sound levels exceeded 163 dB re µPa (rms). This relationship was based on small sample sizes but was later supported by a larger dataset obtained from migrating eastern gray whales (Malme *et al.* 1988). Western gray whales have also been observed to respond to sounds produced during geophysical seismic surveys (Gailey *et al.* Submitted, Johnson *et al.* Submitted, Weller *et al.* 2002, Würsig *et al.* 1999, Yazvenko *et al.* Submitted). One study found that whales traveled faster, changed directions of movement less, moved further from shore, and stayed under water longer between respirations when exposed to higher received sound levels (Gailey *et al.* Submitted). Similarly, Weller *et al.* (2005) found that whales traveled faster and more linearly with short respiration intervals during seismic operations that occurred near the western gray whale feeding grounds in 1997.

During the summer of 2005, SEIC initiated construction of the Piltun Astokh-B (PA-B) platform with the placement of a Concrete Gravity Based Structure, or CGBS. The PA-B platform is located near-shore (~13 km from shore in 30 m water depth) and in close proximity to the Piltun feeding area. The placement of the CGBS consisted of four primary phases: 1) Installation of anchor stations by two anchor handling tug supply vessels (AHTS), 2) CGBS tow-in with five AHTS's, 3) CGBS positioning and placement, and 4) scour protection. Anchor installation commenced on 27 July 2005, two weeks after the start of the behavioral monitoring program, and after placement of the CGBS on August 1 (Phase 3), additional offshore construction activities and scour protection continued throughout the remainder of the behavioral observation period that ended 7 September 2005. Because of the proximity of the platform location to the Piltun feeding area and the potential for adverse impacts on whales caused by sounds generated during the CGBS installation, SEIC developed an industrial sound mitigation strategy prior to placement of the CGBS. SEIC's mitigation strategy included model predictions of the acoustic footprint and associated acoustic and behavior monitoring programs before and during the offshore activities (SEIC 2005).

Monitoring effort in 2005 was a continuation of research conducted in 2001-2004, that aims to provide long-term observations of habitat use, distribution, movement, and behavior of individuals and groups of western gray whales in the Piltun feeding area. Behavioral observations were conducted from onshore stations that were some distance from the whales. Using onshore stations for behavior observations avoided the possibility that activities on the observing platforms were themselves a source of disturbance. In

2005 and earlier years, three primary observation methods were: 1) scan sampling to obtain relative abundance estimates, distribution, and group size information; 2) theodolite tracking of individuals or groups to describe spatial movement, orientations, speeds, and habitat use; and 3) focal animal observations to monitor surfacing-respiration-dive parameters and other surface-visible behaviors.

The 2005 behavior monitoring field season commenced on 12 July 2005 and ended on 7 September 2005. Behavioral monitoring was conducted on every day with acceptable weather / visibility. The field season yielded 26 days of effort, 92 scan samples with 509 sightings of 697 whales, 172 theodolite tracklines encompassing 9,106 geographic positions over 154 hours of tracking, and 67 focal animal follows of individual gray whales over 56 hours of behavioral observations.

Immediately after the 2005 field season and prior to the availability of underwater acoustic data, univariate analyses were conducted using broad categorical measures of industrial activities (Gailey *et al.* 2006). Whale locations, movements, and behaviors were analyzed relative to temporal and spatial categories such as “before placement”, “during placement but at distance from it”, and “during placement but near it”. In these initial univariate analyses, observations that were recorded “during placement but at a distance from it” were taken as undisturbed, while data recorded “during placement but near it” were taken as potentially affected by industrial activities surrounding the CGBS. In addition, Gailey *et al.* (2006) analyzed whale locations, movements, and behaviors relative to measures of research vessel activity. In these analyses, behavioral observations were classified into two categories based on: (1) those with large research vessels within 2 km of the whale, and (2) those with small “Zodiac” type inflatable vessels within 0.5 km of the whale. The large research vessels were conducting ship based abundance and distribution surveys, and as a support vessel for smaller zodiac vessels mainly involved in photo-identification studies.

Results of these initial analyses indicated no significant differences in the number of whales or whale groups before and during construction of the CGBS and scour protection activities. In addition, no significant differences in any respiration parameters were found before and during offshore construction activities for whales observed from the two southernmost stations (nearest the construction activity). There were no significant differences in occurrence, respiration, or movement parameters when large research vessels approached within 2 km of focal whales; however, a significant increase in acceleration was observed when research photo-ID zodiac vessels approached within 0.5 km, indicating that targeted whales changed (increased) speed as the vessel approached. In addition, whales tended to increase their speed, and speed was more variable, when the research Zodiac was nearby (3.4 $\pm$ 3.16 km/h, n=9) as compared to other vessels (1.7 $\pm$ 0.92 km/h, n=8) and no vessels (2.2 + 1.58 km/h, n=124), but these differences were not statistically significant.

Conclusions of the initial analyses were subject to a variety of assumptions and caveats. In particular, the analytical technique used to avoid potential effects of autocorrelation substantially reduced sample size in all groups. It was recognized that the initial analysis needed to be expanded to remove as many assumptions as possible and to increase statistical power. Toward this end, we incorporated additional natural and anthropogenic variables to better explain background variation, and employed more sophisticated statistical techniques to account for autocorrelation without unduly sacrificing the ability to detect industrial effects on western gray whale behavior.

The current analytical approach applies multiple-predictor regression analysis to overcome the short-comings of the initial univariate analyses. We chose multivariate regression over alternative methods for several reasons. In 2001, we found non-significant results for univariate analyses investigating the effects of transient (seismic) sounds produced during geophysical seismic surveys, but after accounting for environmental and temporal factors in a multivariate regression, several behavioral variables were found to be significantly associated with sound exposure (Würsig *et al.* 2002, Gailey *et al.* Submitted). In those regression analyses, five of eleven behavioral variables were statistically correlated to sound related variables, while six behavioral variables were not correlated with sound variables. In addition, regression afforded greater statistical power because more sophisticated techniques were available to account for autocorrelation between subsequent bins of the same track or focal-follow observation. This approach allowed us to increase the number of observations included in the analysis and thereby increased both accuracy and precision of the analysis. In contrast, our univariate approach randomly selected one representative bin from each track or focal-follow to avoid effects of autocorrelation, which obviously resulted in reduction of statistical power and ignored a substantial amount of within-track/focal-follow information.

Objectives

The primary objective of the current analyses is to evaluate behavioral response indicators and their relationship to underwater industrial sound levels of the 2005 offshore construction season in the Piltun feeding area during the whales' primary foraging period (July – September). Research vessel activity also occurred near and in the Piltun feeding area and the effects of these vessels on whale behavior were also evaluated. We sought to accomplish these objectives using an analysis that accounted for sources of natural variation prior to assessment of industrial effects. As such, the current multivariate regression analysis incorporates non-industrial environmental factors, temporal factors, spatial variables, and vessel effects (number and distance to vessels). Distance of the whale from the CGBS installation site and sound levels were used to examine impacts that industrial operations and other sources of anthropogenic activities may have had on western gray whales. These explanatory variables were applied separately to explain variation in a total of thirteen individual behavioral response variables related to movement and surfacing-respiration-diving.

A better understanding of the short and longer-term reactions of whales to certain types and levels of anthropogenic activities was needed to address the second objective. The second objective is a short-term monitoring system that allows investigators and managers to accurately identify aberrant whale behavior in real time. In this context, aberrant behavior is defined as behaviors that exceed the known range of movement and respiration parameters that were observed in the absence of anthropogenic activity (i.e.

“natural” behavior). For example, it may be possible to detect when the combined variables of increasing acceleration, changes from feeding to traveling, and increased respiration rate have passed a behavioral threshold in response to sound level or vessel presence into what would be considered aberrant from historical baseline records. Ideally, this type of monitoring would rapidly assess whale behavior and human activities in real time in such a way that relevant information could be disseminated to authorized personnel and appropriate actions could be taken immediately when and if a whale’s behavior was identified as aberrant. It is our hope that the current multivariate regression analyses will inform this "real-time monitoring" scheme.

Methods

Details of data collection methods for acoustics and behavioral research were outlined in Rutenko (2006) and Gailey *et al.* (2006), respectively, and are not repeated in this report. Relevant information on sound level estimation and analytical approach is provided in Appendix A and B.

Behavioral monitoring

Before and during the CGBS installation, western gray whale behaviors, respiration, and movement patterns were monitored from shore (see Gailey *et al.* 2006). For this report, we used theodolite tracking and focal follow information to evaluate gray whale movements and respiration-related activities. Scan data were used to provide supplemental insight in relation to distance from shore results from our movement data, since scan data are more likely to be representative of whales in a region at the time of observation. A total of seven movement and six respiration variables were derived from trackline and focal animal observations (

Table 1). Collectively, we call these 13 behavior variables “the response variables”. To standardize units for analysis, response variables were calculated for every 10.5 minute interval (hereafter referred to as a ‘bin’) of continuous observation. Because many response variables (such as linearity and reorientation rate) are not instantaneous measurements, some time was required to derive the response variables. We arbitrarily chose bins of 10.5 minutes in length as a compromise between allowing adequate time to acquire data upon which responses could be measured and the need to assess short-term behavioral responses. Similar length bins have been used in the past (Gailey *et al.*, submitted) and proved adequate for meaningful analyses. Prior to computing responses for each bin, all movement data were resampled every 90 seconds to avoid under- or over-sampling issues and to standardize step lengths of movement (see Gailey *et al.* submitted, Turchin 1998). This resampling allowed for standardized responses by connecting all observations of an individual through time, and then placing a point on this interpolated path every 90 seconds. If several observations were recorded within, as an example, 20 seconds of each other during a single resurfacing event, the resampling scheme used those observations to establish a path progressing through those observations, but placed points along the path at 90 second intervals. A 90 second resampling interval was chosen based on an autocorrelation analysis of the movement data that indicated that correlation died out on average around 90 seconds (Würsig *et al.* 2002). This resampling procedure produced seven spatial points per bin. Bins that did not yield adequate data for the entire 10.5 min. duration (i.e. the last bin in a sequence of bins of a single trackline) were removed from the dataset. For each these bins, several response variables were calculated (Table 1).

Table 1. Description of the response variables derived from track line and focal follow observations. Movement variables were derived from track lines. Respiration variables were derived from focal follow observations.

	Variable	Definition
Movement Parameters	Leg Speed	Distance traveled between two sequential fixed points within a trackline divided by the time interval between the two points
	Acceleration	Changes within leg speed to determine if an animal is generally increasing or decreasing speeds within a trackline
	Linearity	An index of deviation from a straight line, calculated by dividing the net geographic distance between the first and last fix of a trackline by the cumulative distances along the track
	Mean Vector Length	A directionality index r (Cain 1989) dependent on angular changes - range from 0 (great scatter) to 1 (all movements in the same direction)
	Reorientation Rate	Magnitude of bearing changes, calculated by the summation of absolute values of all bearing changes along a trackline divided by the entire duration of the trackline in minutes
	Distance-from-Shore	Distance of animal from the closest perindicular distance from the nearby coastline
	Ranging Index	Measure of the minimal diagonal area of the whale's track incorporating its course and track duration (Jahoda *et al.* 2003)
Respiration Parameters	Respiration Interval	Duration less than 60 s between subsequent exhalations per surfacing
	Dive Time	Any interval where exhalation period is greater than 60 s
	Surface Time	Duration the animal remains at or near the surface
	Number Blows/Surfacing	Total number of exhalations per surfacing
	Surface Blow Rate	Mean number of exhalations per minute during a surfacing
	Dive-Surface Blow rate	Number of exhalations per minute averaged over the duration of a surfacing-dive cycle, using the dive previous to the surfacing

Independent variables, used to explain variation in movement and respiration activities, were categorized into two classes: 1) natural variables, and 2) impact variables (Table 2). The class with natural variables consisted of environmental, temporal, and the behavioral state of the animal (i.e. feeding, traveling, feeding/traveling, or mixed).

Environmental variables included the observation station, date, time of day, behavioral state, Beaufort sea state, visibility, distance-from-station, water depth at the animal's location, tide height, wind speed, wind direction, estimated swell height, and air temperature for each observation bin. Station, behavioral state, and wind direction are categorical (discrete) variables and were included as factors. These variables were coded as a set of 0-1 indicator variables (i.e. either have a value of 0 or 1) that measured effects of changing from one category to another relative to an arbitrary reference. For example, observations were recorded from six stations. The factor effect for station was coded as a set of five indicator variables, the first being 1 if an observation was from 1st Station, 0 otherwise, the second being 1 if an observation was from 2nd Station, 0 otherwise, and so on. No indicator variable was constructed for South Station because it was the reference level. The effects of South Station were therefore included in the intercept of the regression, and the effects of other stations were measured relative to those of South Station. That is, a coefficient of β for 1st Station implied that the predicted response value at 1st Station was β units different from the predicted value at South Station, assuming all other variables were the same at both.

The behavioral state of gray whales was associated with each bin and classified as one of the following four levels: Feeding, Feeding/Traveling, Traveling, and Mixed. Classification of behavior into one of these four categories was based on field observations regarding a whale's predominant behavior at the time. Feeding behavior was characterized by non-directional movement where whale(s) generally remain in one localized area with consistent periods of diving. Traveling behavior was characterized as swimming in one general direction and often remaining at the surface without consistent dives. Feeding/Traveling behavior consisted of whale(s) swimming at relatively slow speeds with consistent periods of diving and having directional persistence in movement. Mixed behavior was any combination of unknown, transitional behaviors, or unrecognized behaviors comprising a substantial portion of the bin.

The class of impact variables included both anthropogenic sound variables, and variables associated with vessels. Impact variables were approach distance of the closest vessel of any type, distance from the whale to the PA-B CGBS installation, number of vessels within 5 km of the whale, underwater sound level received at a nearby grid point (see Appendix A), and underwater received sound level combined with shoreward distance of the whale from the nearby sound prediction point (Table 2).

Distance of closest approach by any research vessel was coded as a factor containing the following five levels: 0 km to 0.5 km, 0.5 km to 1.0 km, 1.0 km to 2.0 km, 2 km to 5 km, and greater than 5 km. We treated distance of closest research vessel approach as a factor, rather than a single continuous variable, because distance measurements to vessels greater than 5 km were not available for all vessels operating in the area. This lack of vessel positional data beyond 5 km in distance is relatively inconsequential for the results because its factor coding provided a flexible fit to response variables, and any impact vessel proximity may have had on gray whales were expected to be higher as the vessel approached the whale and relatively low beyond 5 km. Vessel types were not considered in these analyses; however, large vessels involved in offshore construction were always outside the feeding area (~13 km from shore at the CGBS/PA-B site) and never approached whales within 5 km. Whales sometimes occurred within 5 km of large research vessels, but these events were short in duration. Virtually all vessels approaching within relatively close distance, < 2 km, of a whale were small (Zodiac) type research vessels.

Computation of received sound levels at a nearby point involved propagating sound levels received at eight hydro-acoustic recording stations (AUARs) to a grid of prediction points spaced 1 km apart (see Figure A.1 in Appendix A). The average sound level was then calculated over each temporal bin at the nearest prediction point to the whale's location. Details of the prediction grid, recording stations, propagation approach and verification are provided in Appendix A. In addition to the estimated sound level at the nearest grid point, we considered a variable that included the shoreward (perpendicular to coast) distance of the whale to the grid point as a proxy of sound propagation loss. The maximum straight-line distance of a whale to the nearest grid point location was 0.7 km. Shoreward distance was expressed as a negative value if the whale was inshore of the prediction point, and positive if the whale was offshore of the prediction point. Therefore, the combination of nearest grid point location and shoreward distance was our best estimator of received sound level at the animal's actual location. Along shore (parallel to shore) distances from the grid point to the whale's location were not considered because the distribution of sound sources along shore was variable and not well known.

Table 2. Environmental and impact variables used to explain variation in movement and respiration activity of western gray whales.

Variable type	Variable	Description	Coding
Natural	Station	Name of observation station where whale was observed	Factor with six levels: South station 1st station 2nd station Station 07 Odoptu station North station South station was the reference level.
	Date	Day of the season	Number of seconds from 00:00:00 1Jan1970 to 00:00:00 of the study day in 2005.
	Time of day	Time of the observation	Time of the observation, coded as hours after 00:00:00 of the same day. E.g., an observation at 3:41:15pm on any
	Behavior	Animal's behavioral state during observation bin	Factor with four levels: Feeding Feeding/Traveling Traveling Mixed (other) Feeding was the reference level.
	Beaufort	Sea state measured on Beaufort scale	0, 1, 2, 3, or 4. Fitted as a linear (1 coefficient) effect.
	Visibility	Visibility conditions estimated at the time	1, 2, 3, 4, or 5. Fitted as linear (1 coefficient) effect.
	Distance to station	Distance from whale location to the onshore observation station (m)	
	Depth	Water depth at whale location (m)	
	Tide	Predicted tide height at time of observation (m)	Predicted tide height at time of observation (meters)
	Wind direction	Direction of the wind	Factor with four levels: South = “S”, “SE”, “SES”, “SSE”, “SSW”, “SW”, “SWS” West = “W”, “WNW”, “WSW”, “NWW” East = “E”, “ENE”, “ESE”, “NEE” North = “N”, “NE”, “NNE”, “NNW”, “NW” South was the reference level.
	Wind speed	Speed of the wind (km/h) during observation	
	Swell	Field estimated swell height (m) during observation	
	Temperature	Air temperature at time of observation (°C)	
Impact	Closest vessel	Distance from whale to closest vessel (km)	Factor with five levels: [0,0.5] : distance 0 to 0.5 km (0.5,1] : distance >0.5 to 1.0 km (1,2] : distance >1.0 to 2.0 km (2,5] : distance >2.0 to 5.0 km (5+] : distance >5.0 km [0.0.5] was the reference level. No vessels in the vicinity
	CGBS distance	Distance from CGBS location to whale (km)	
	Number of vessels	Total number of vessels within 5 km of the whale (range 0 to 3)	Fitted as a linear (1 coefficient) effect.
	Sound level	Predicted underwater sound level (dB re 1 m Pa) at nearest sound prediction grid point during the 10.5 minute interval. Sound prediction grid covered study area and contained points spaced 1 km apart. Underwater sound levels received at recording buoys were propagated to each point in the sound prediction grid.	
	Sound level + shoreward distance	Combination of sound level and shoreward distance to the nearest grid point as a proxy of received sound levels at the whale's location. Shoreward distance = distance (km) perpendicular to shore from whale location to the east-west coordinate of the nearest sound prediction grid point.	Fitted as 2 coefficients.

Multivariate Regression Analyses of WGW Behavior

The objective of the multivariate regression analyses was to evaluate potential associations between western gray whale behavioral responses and anthropogenic activities in the area. The primary focus was on potential impacts associated with sounds produced during the CGBS-installation, but we also investigated the impacts of research vessels operating in or close to the feeding area. To accurately identify impacts, it was necessary to control or account for natural variation in behavior prior to assessing anthropogenic impacts. The modeling techniques were chosen due to the nature of the objectives and because autocorrelation was present in the response variables. An overview of our analytical approach is outlined below and a more conceptually detailed section on the analyses is provided in Appendix B.

The analytical dataset consisted of 125 tracklines and 66 focal animal follow observations collected between 13-Jul-2005 and 6-Sep-2005. The 125 tracklines consisted of 705 bins, and the 66 focal animal observations contained 289 bins. In some bins, certain variables could not be measured, primarily because focal animals did not dive during the observation period or no acoustic data were available; consequently, the actual number of bins used for estimation varied depending on the response variable being analyzed. The bins observed for each individual were consecutive (i.e. potentially autocorrelated) within one track/focal session and varied in number among tracking/focal sessions. Standard multivariate regression methods, augmented with weighting (see below) and block permutation methods (Appendix B), were applied to investigate anthropogenic impacts. Weighting was used to correct for unequal representation of whales displaying different behaviors, those at different offshore distances, and those observed during different weather conditions. We were, for example, more likely to observe whales close to the observation station, and for longer periods during clear weather, and consequently these whales were down-weighted in the analysis. Block permutation was used to adjust for temporal autocorrelation in responses. An added benefit of block permutation was that the statistical significance levels produced by the analysis were nonparametric and, therefore, did not depend on distributional assumptions. Block permutation, however, performs better (converges to the correct significance level quicker) when response distributions are roughly unimodal and symmetric. We therefore transformed several response variables to produce symmetric and normal-looking distributions.

Response Variable Treatment

The permutation methods employed in the regression analysis perform better when response distributions are roughly unimodal and symmetric. We therefore sought transformations that yielded distributions that were unimodal , symmetrical, and contained as few outliers as possible. We determined appropriate transformations for each response by visually inspecting box-plots categorized by a whale's behavioral state (feeding, traveling, feeding/traveling, or mixed). Transformation procedures applied to each response variable are listed in Table 3. Two variables (linearity and mean vector length) were transformed using the logistic transformation even though these variables were not strictly binomial. Because some of the raw values were 1.0, a small constant was added to all values of these variables in order to compute the logit. This constant was 0.5 (1-[largest value < 1]), which is small enough to have an inconsequential effect on results.

Table 3. Transformations applied to response variables. Transformations were chosen to yield approximate symmetric distributions with as few outliers as possible. All logarithms were natural logarithms (i.e., base *e*).

Response Type	Response Variable	Transformation
Track line	Speed	Square root: sqrt.speed = $\sqrt{\text{speed}}$
	Acceleration	No transformation
	Linearity	Logit: logit.linearity = log[(linearity – c) / (1 – (linearity – c))], where c = 0.0001722 was used to prevent division by 0. Constant c equaled ½ difference between largest linearity <1.0 and 1.0.
	Mean Vector Length	Logit: logit.mvl = log[(mvl – c) / (1 – (mvl – c))], where c = 0.00005 was used to prevent division by 0. Constant c equaled ½ difference between largest mvl <1.0 and 1.0.
	Reorientation rate	No transformation
	Range	Log: log.range = log(range)
	Distance from shore	No transformation
Focal-follow	Blow Interval	No transformation
	Surface time	Log: log.stime = log(stime)
	Dive time	Log: log.divetime = log(dive.time)
	Blows per surfacings	Log: log.bps = log(bps)
	Surface blow rate	Log: log.srate = log(srate)
	Dive-Surface blow rate	No transformation

Pair-wise Pearson correlation coefficients (Table B.1 *in* Appendix B) were computed between all 1) continuous natural covariates and continuous impact variables and 2) non-continuous natural variables (i.e. factors) and continuous and non-continuous impact variables to evaluate potential correlation between these different variables (Table 2). For all continuous variables, none of the correlation coefficients were sufficiently large enough (> 0.60) to warrant concerns that natural variables were masking impact effects, or *vice versa*, in the regressions.

Box-plots (Figures B.1-B.9 *in* Appendix B) were constructed for the non-continuous natural variables and continuous and non-continuous (i.e., factors) impact variables. With the exception of distance to the CGBS location and observation station, these box-plots presented no evidence of strong correlation. Being strongly associated with one another, station and distance to CGBS were not allowed to enter into the same model. As expected, distance to the CGBS location was small for whales observed from southern stations, and large for whales observed from northern stations because the CGBS was located directly offshore of the southern stations.

Model Estimation and Selection

Movement responses were recorded on tracklines consisting of 1 to 33 consecutive bins (33 bins = 5.7 hrs). Focal animal follow data consisted of responses measured from 1 to 16 consecutive bins (16 bins = 2.8 hrs). The number of bins observed per animal was influenced by the ability to continuously track or follow whales for extended periods of time. The ability to continuously follow whales was a function of limited or decreased visibility due to fog, high sea state, rain, or other inclement weather. In addition, animals initially closer to the observation station were more likely to be chosen to be tracked/followed,and were more likely to be observed for longer periods, than animals further from the station, suggesting some distance-based inclusion bias. Whatever the source, whether induced by variable ability to track whales, behavior, or sightability, these factors caused observations from whales close to station to have higher probability of being included in our sample, and to contribute more bins per tracking session (on average), than animals far from station. This implied potential sampling bias in the behavioral observations. In this case, the bias was toward including too many observations of whales that were easy to track or that were sighted during good weather close to shore and station. Conversely, too few observations of difficult to track whales sighted far from the observation station and shore were included.

The probability that we obtained a bin from a whale was strongly correlated with the number of bins that were actually observed. If probability of obtaining an observation was high, we tended to observe more bins. If probability of obtaining an observation was low, we observed fewer bins. Furthermore, the number of bins likely to be observed was different for different behavioral classifications. For example, we were more likely to have more representative bins for a feeding whale (animals remaining in a localized area) than a traveling whale (animals traversing across the study area). If inclusion probabilities were not correlated with the observed number of bins, researchers would have observed approximately equal numbers of bins for whales displaying similar behaviors (i.e., feeding, traveling, etc.) and at different offshore distances, which was clearly not the case.

To adjust for this bias, we weighted each observation in subsequent multivariate regressions by a value inversely proportional to the probability of obtaining that observation. The use of weighting was justified by the Horvitz-Thompson theorem (Horvitz and Thompson 1952; Overton and Stehman 1995), which states that weighted averages provide unbiased estimates of population means when weights are inversely proportional to probability of including the observation. Based on this theory, each behavioral observation (bin) was weighted by the inverse of the total number of bins observed from the whale. In other words, all observations in the regression analyses were weighted by $1/n_i$, where n_i equaled the number of bins observed from animal *i*. As a result, each animal in the analyses had a total weight of 1.0.

To match the impact related objectives of this study, model selection was performed in two phases. First, as much natural behavioral variation as possible was explained to reduce the overall amount of unexplained variation in the response variables. Then, impact variables were added (one at a time) to the model to examine if the variable explained a significant proportion of the remaining variation. If an impact variable explained a significant proportion of the remaining variation, the response was considered to be associated with the impact variable. The logic behind this two phased model selection approach is discussed in greater detail in Appendix B. In the remainder of this section, we describe both model selection phases:

Phase I - During the initial phase of model selection, stepwise Bayesian Information Criteria (BIC) selection was used to identify a reasonable model containing natural effects only (Table 2). Stepwise selection of natural effects consisted of both forward and backward steps. Each forward step started with the model resulting from the previous step, and added natural variables not already in the model, one at a time. The BIC was computed for each model, and the variable that reduced BIC the most was added to the current model. If no variable reduced BIC, stepwise selection was stopped and the current model was fixed as the final model. Following this forward step process, a backward step process was conducted whereby all variables already in the current model were dropped one at a time. BIC was recomputed from each reduced model, and if removal of at least one variable reduced BIC, the variable that reduced BIC most was removed from the model. The initial model contained an intercept only. Estimation was conducted by the method of least squares. No adjustment for autocorrelation was attempted during this phase because p-values were not computed and autocorrelation, if present, is known to have little effect on model coefficients.

Phase II - Following Phase I, phase two of model selection added all impact variables one at a time to the model resulting from Phase I (Table 2). The amount of additional variation explained by each impact variable, and the resulting drop-in-sum-of-squares F statistic, were computed. Significance of the F statistic was computed by block permutation (Appendix B) to mitigate the effects of autocorrelation and non-normality of responses. Significance of any impact variable's F statistic indicated that the variable explained a significant portion of behavioral variation that could not be explained by environmental and temporal considerations.

Phase II of model selection resulted in separate tests for each impact variable in models for each response. A total of five impact variables were considered in models for 13 responses, yielding $5 \times 13 = 65$ tests at the end of Phase II. If all 65 tests were truly independent, we would expect approximately three of these tests to be significant (at the $\alpha = 0.05$ level) if all impact variables were truly unrelated to all responses. For reasons discussed in Appendix B (Section *Experiment-wise Significance Levels*) we did not attempt to correct each individual tests to control the overall experiment-wise significance level, rather we argue that 1) conclusions needed to be specific rather than broad, 2) an acceptable method for correcting tests could not be identified due to unknown correlations among responses and impacts, and 3) the set of unadjusted tests were conservative in the sense that they too often declare an impact on behavior to be present when in fact it is not (see Appendix B for further details). From the standpoint of western gray whale conservation, the overall set of tests is a conservative approach as it errors on the side of overpredicting possible effects on the whale.

Results

Sample Size/Effort

Behavioral research was conducted from 12 July to 7 September 2005 at six observation stations near the primary feeding region for western gray whales. These observations occurred during two of four primary stages of CGBS installation (Anchor Installation and Scour Protection). Unfortunately, weather conditions (primarily fog) hampered the behavioral research effort during the other two stages (CGBS tow-in and positioning and placement). Sounds produced during other activities of the CGBS installation and other vessels in the region were monitored continuously throughout the field season by the acoustics monitoring team from the Pacific Oceanological Institute, Vladivostok (Rutenko 2006).

Focal and movement observations consisted of 289 bins of 66 focal-follow observations and 705 bins of 125 tracklines. Available acoustic information overlapped with 93% (268 bins) of the focal data and 90% (639) of the movement dataset. Bins that contained no sound levels (i.e. 21 bins of 9 focal-follow observations and 66 bins of 16 tracklines) were removed from the datasets. The majority of the observation data that did not coincide with acoustic information occurred during the initial period of 13-15 July 2005, and the remainder during short periods of 6, 23, and 31 August. Absence of acoustic information during these periods was in most instances the result of missing positional information for the research vessel operating in the area (required to adjust model estimates of the noise field); in a few instances it was caused by a gap in the sound level recordings (due to AUAR maintenance) at a station sufficiently close to the whale's position to allow reliable estimation.

Natural Models

Of the 14 explanatory variables of natural variation in western gray whale behavioral responses, behavioral state of the whale (feeding, feeding/traveling, traveling, and mixed) was the most dominant predictor for five of the movement variables and three of the focal-follow variables. In general, coefficients of the natural models (Table 4) indicate that gray whales' speeds increased, linearity increased, mean vector length increased, reorientation decreased, range index increased, blow interval increased, surface time increased, and surface blow rate decreased when whales changed from feeding activity to feeding/traveling. The same effects in the same directions occurred again when whales changed from feeding/traveling to traveling. Behavioral states were not strongly associated with acceleration, distance from shore, dive time, blows/surfacing, and dive-surface blow rate.

For dive time and distance from shore responses, water depth was the only natural explanatory variable that entered into the models at the end of Phase I. Coefficients in these models indicated that dive time and distance from shore increased as depth increased (Table 4). Water depth generally increases in the area as a function of distance from shore, and gray whales appear to have spent more time underwater, potentially related to bottom-feeding activity, in deeper waters. Distance from station was associated with the number of blows per surfacing (Table 4). The coefficient for distance to station indicated that as distance from the station increased, number of blows per surfacing increased. Wind speed explained a large amount of variation in the dive-surface blow rate

(Table 4), with an increased rate (i.e. # of blows per dive-surface duration) being associated with elevated wind speed. None of the natural variables appeared to be strongly associated with acceleration (Table 4).

Table 4. Regression models for natural variation in western gray whale (A) movement and (B) respiration parameters resulting from Phase I of model fitting. Variables selected for inclusion were natural variables only (Table 2) and were chosen by a stepwise BIC procedure. Effects in these models were considered "nuisance" effects for testing of impact variables, and as such no standard errors or significance levels were reported.

A)

	Response						
Variable	Speed	Acceleration	Linearity	Mean Vector Length	Reorientation Rate	Range	Distance from Shore
(Intercept)	0.9667	-0.0101	0.5283	0.0999	35.3643	2.2755	-0.2113
Behavior (Reference = Feeding)							
Feeding/Traveling	0.3107	NA	1.7642	1.5064	-13.8820	0.7668	NA
Mixed	0.5051	NA	1.9809	1.4632	-13.8204	1.0062	NA
Traveling	0.8386	NA	3.1160	3.2687	-25.4219	1.5848	NA
Depth	NA	NA	NA	NA	NA	NA	0.1475

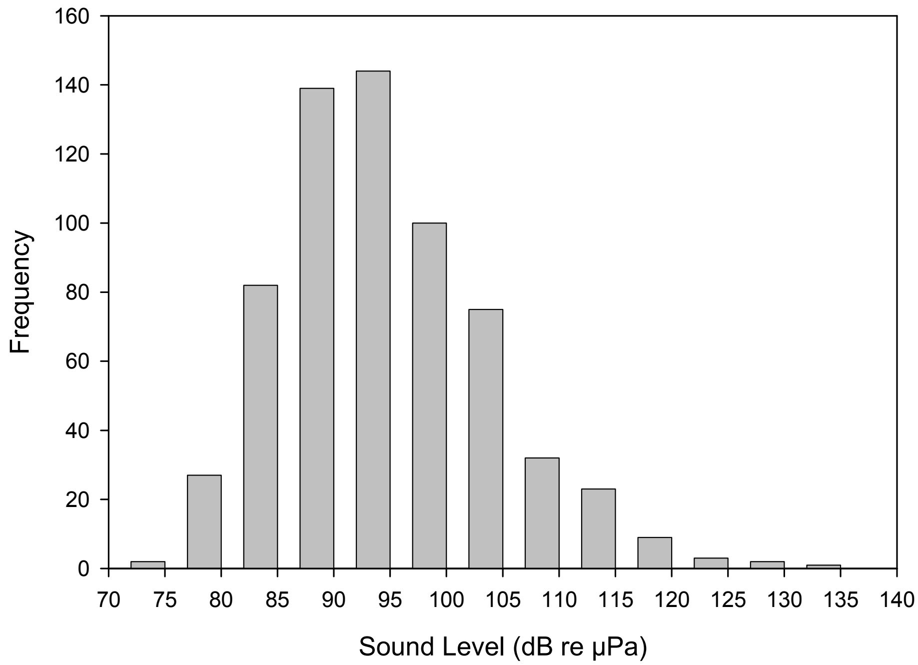
B)

	Response					
Variable	Blow Interval	Surface Time	Dive Time	Blows/Surfacing	Surface blow rate	Dive-Surface blow rate
(Intercept)	0.3129	-0.5282	0.4375	1.1915	1.6172	1.0128
Behavior (Reference = Feeding)						
Feeding/Traveling	0.0216	0.2812	NA	NA	-0.1123	NA
Mixed	0.0965	1.1137	NA	NA	-0.2552	NA
Traveling	0.2072	0.8451	NA	NA	-0.4356	NA
Depth	NA	NA	0.0390	NA	NA	NA
Distance from Station	NA	NA	NA	0.1852	NA	NA
Wind Speed	NA	NA	NA	NA	NA	0.0240

Distribution of Impact Variables during Behavioral Observations

The univariate (empirical) distribution of each impact variable was computed to provide an overall indication of amounts and levels of impact variables to which western gray whales were exposed,. The average acoustic energy levels at the closest grid point to a gray whale's location ranged from 79 to 136 dB re μPa for movement sessions, and 84 to 126 dB re μPa for focal sessions (Figure 1). The closest distance of any observation to the CGBS location was 9.8 km with a maximum distance of 48 km (Figure 2). The closest observed approach between vessels and whales was 20 meters (
Figure 3). The number of vessels within 5 km of a gray whale being monitored ranged from 0 to 3 (Figure 4).

A)


160
140
120
100
80
60
40
20
0
Frequency
70 75 80 85 90 95 100 105 110 115 120 125 130 135 140
Sound Level (dB re μPa)

B)

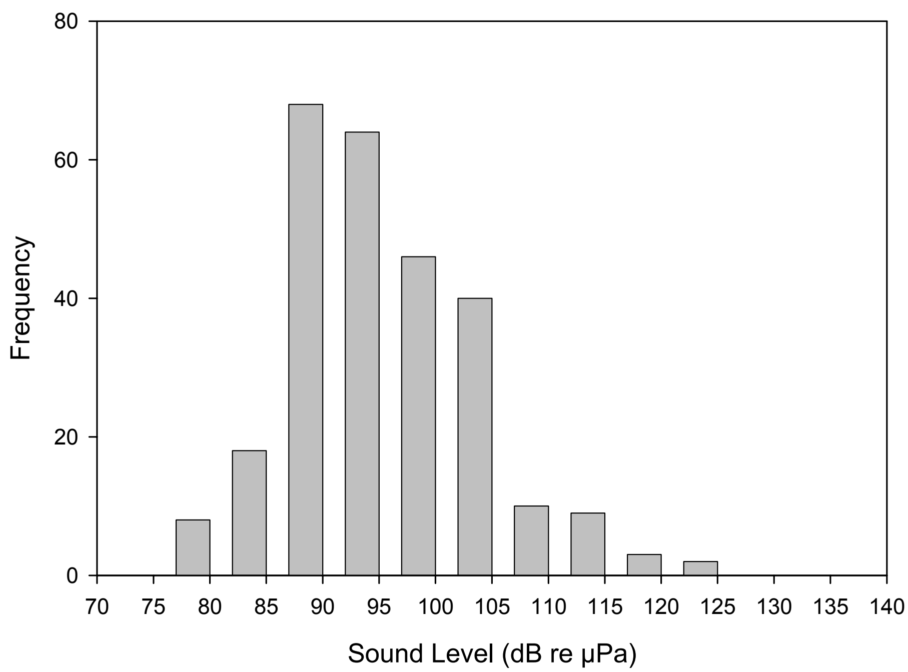
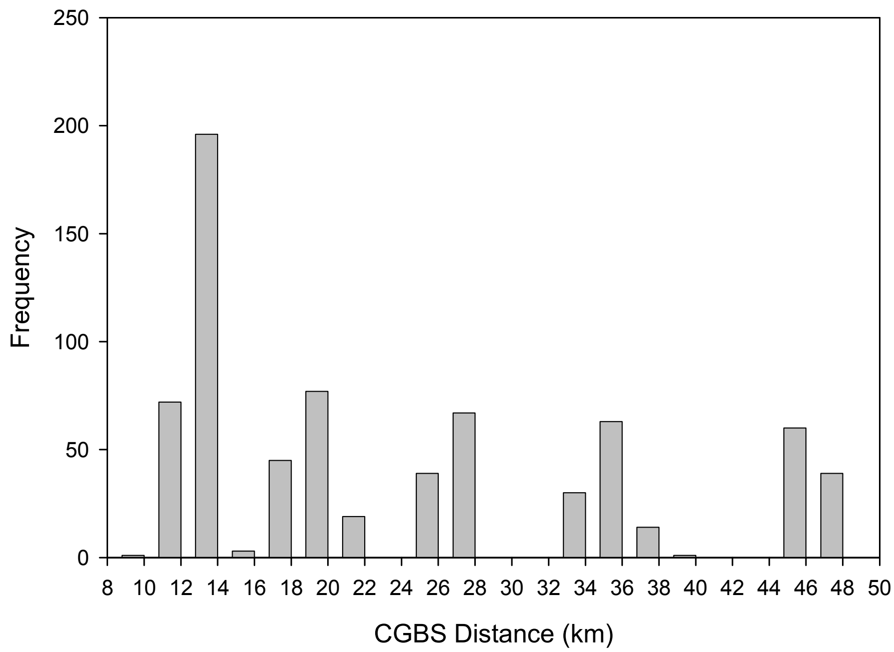

80
60
40
20
0
Frequency
70 75 80 85 90 95 100 105 110 115 120 125 130 135 140
Sound Level (dB re μPa)

Figure 1. Frequency distribution of underwater sound levels during (A) theodolite tracking and (B) focal follow sessions, as estimated at the nearest sound prediction grid point. Sound level values are averages over the 10.5 minute summary bins.

A)



B)

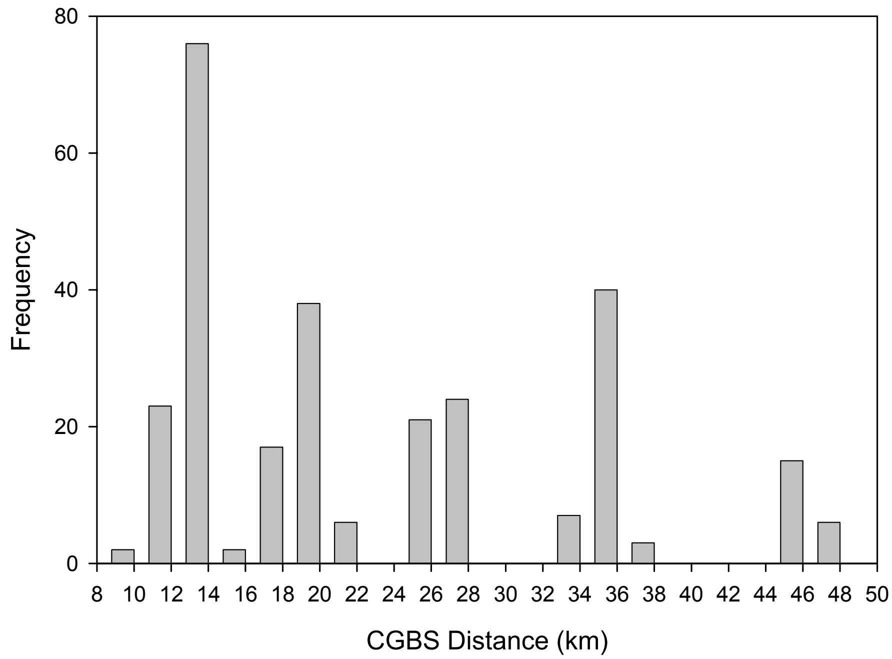
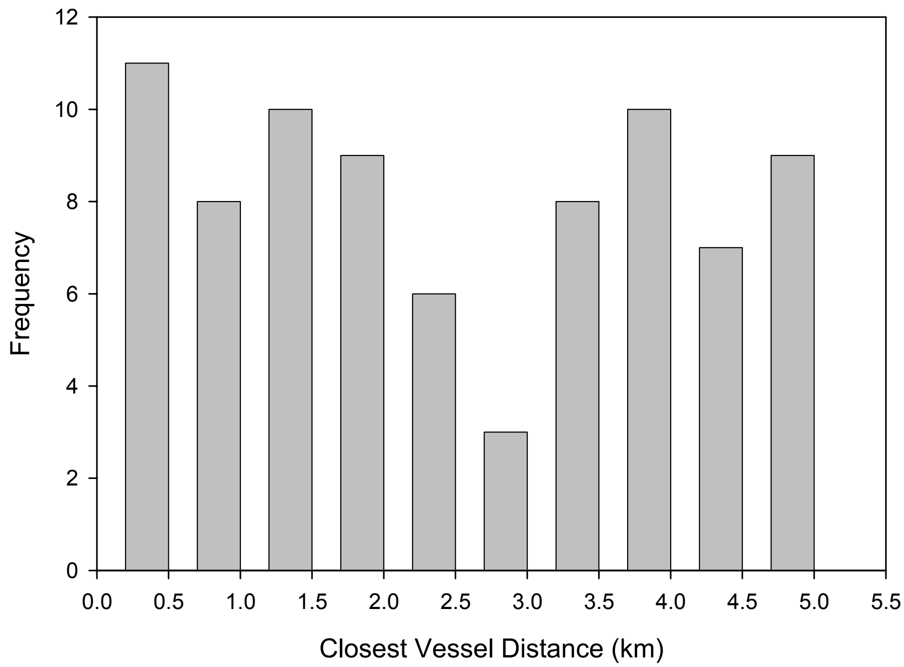


Figure 2. Frequency distribution of distances from gray whales to the (A) CGBS during movement and (B) focal sessions.

A)


12
10
8
6
4
2
0
Frequency
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
Closest Vessel Distance (km)

B)

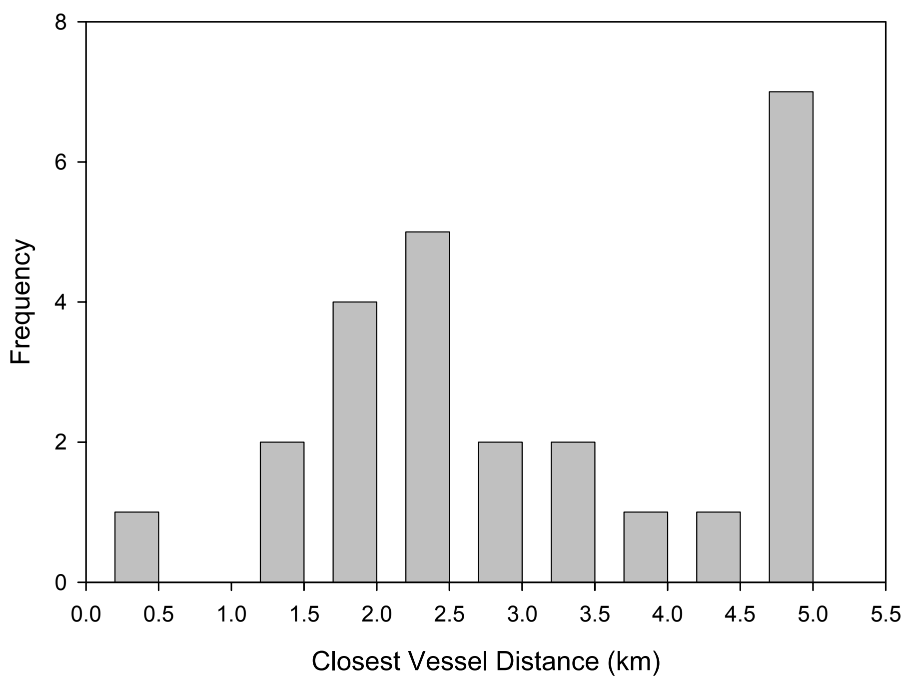
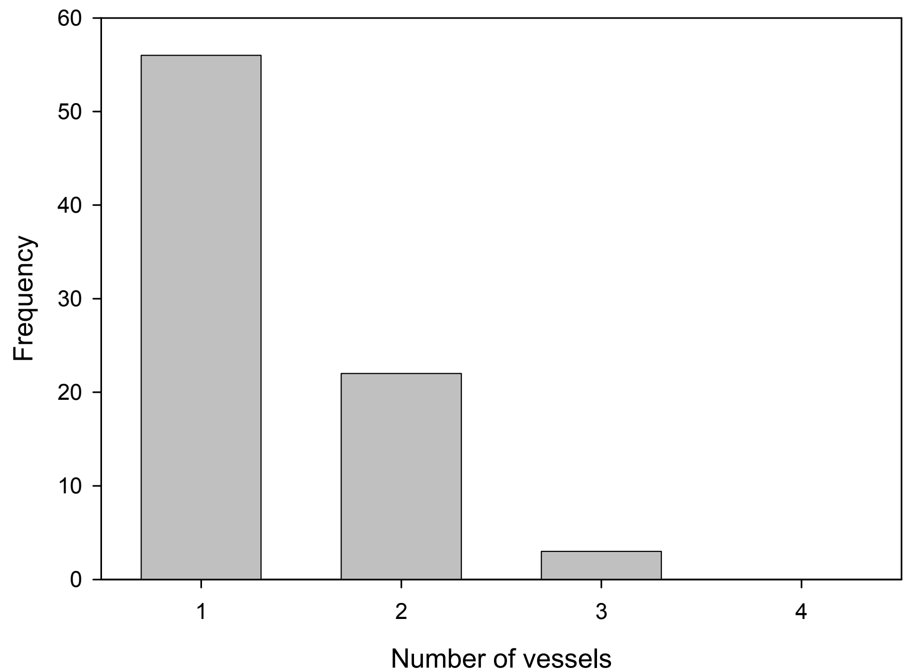

8
6
4
2
0
Frequency
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
Closest Vessel Distance (km)

Figure 3. Frequency distribution of closest approach to a gray whale by any vessel (A) during movement and (B) focal sessions. Distances were measured to within 5 km of a whale. Positional information beyond 5 km was unavailable for each operational vessel; therefore, the closest vessel distance beyond 5 km is unknown.

A)



B)

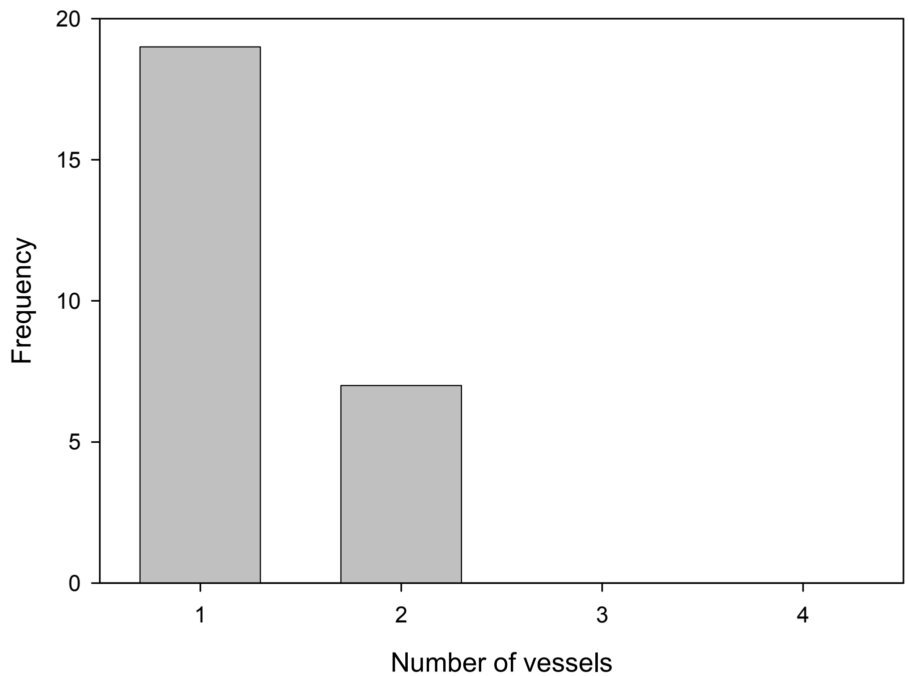
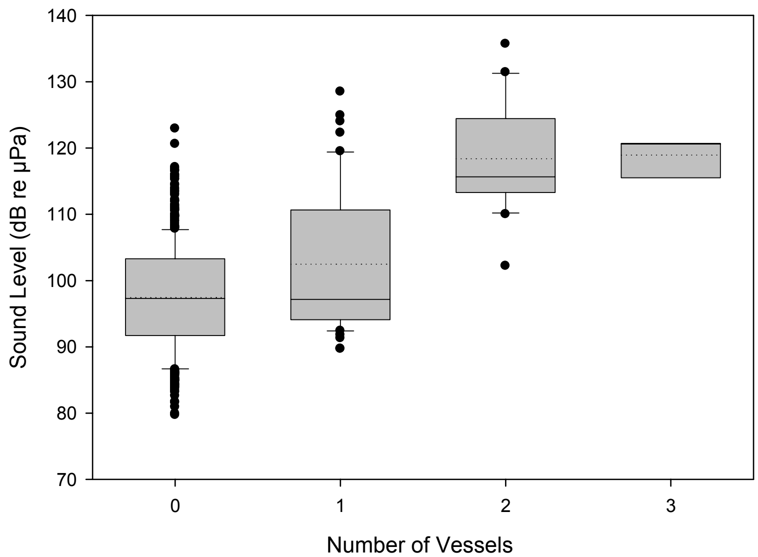


Figure 4. Frequency distribution of number of vessels within 5 km of gray whales during (A) movement and (B) focal sessions.

When one or more vessels were operating <5 km of whales being monitored, sound levels at the nearest grid point locations tend to increase compared to when no vessels were < 5 km of the gray whales (Figure 5 & Figure 6).

A.



B.

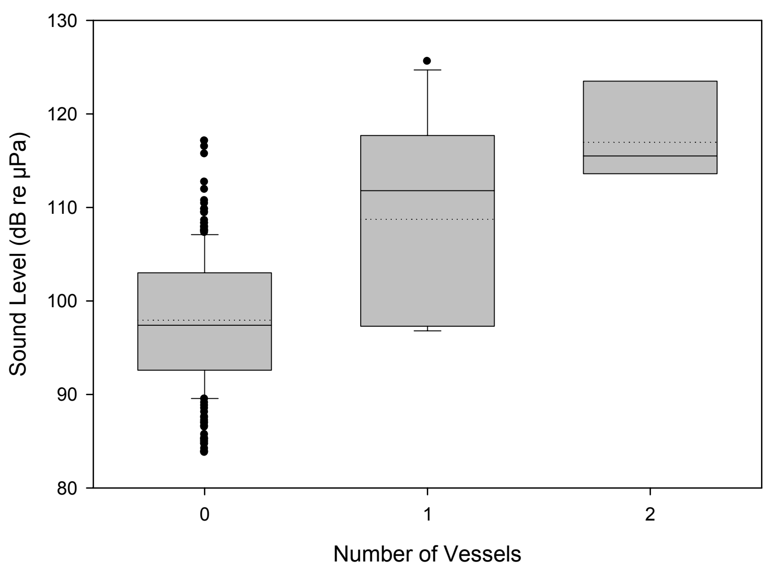
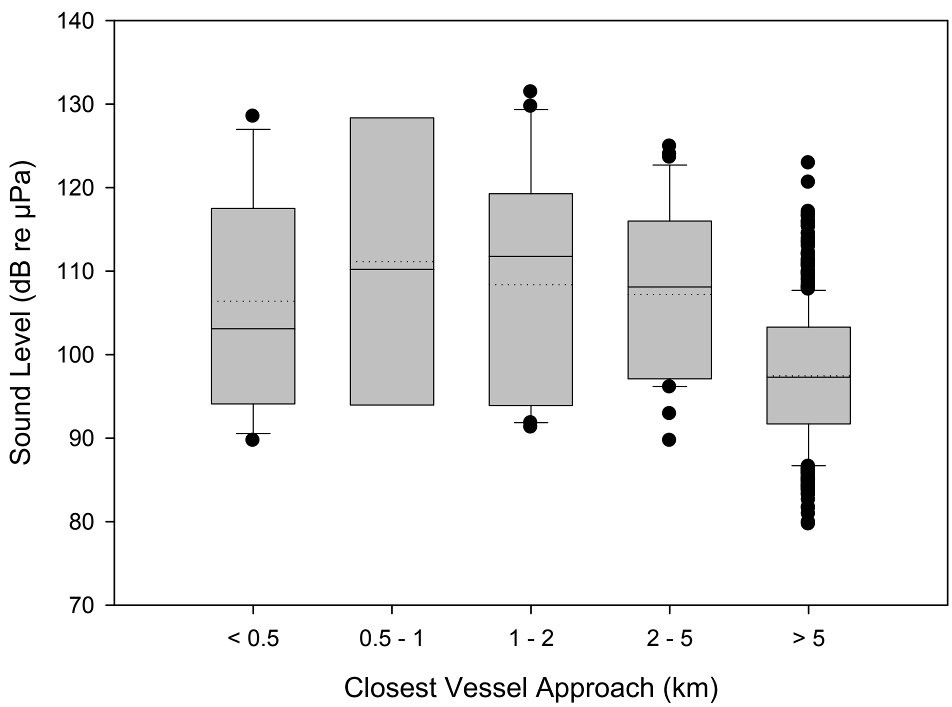


Figure 5. Box-plots representing the distribution of received underwater sound at the prediction grid point closest to a monitored whale when 0, 1, 2, and 3 vessels were operating within 5 km of the whale when (A) movement data and (B) focal animal observations were being recorded. For each box-plot, the whiskers represent the 10th and 90th percentile, the box represents the 25th and 75th percentile, the solid line represents the 50th percentile, and dotted lines represent mean values.

A)


140
130
120
110
100
90
80
70
Sound Level (dB re µPa)
< 0.5
0.5 - 1
1 - 2
2 - 5
> 5
Closest Vessel Approach (km)

B)

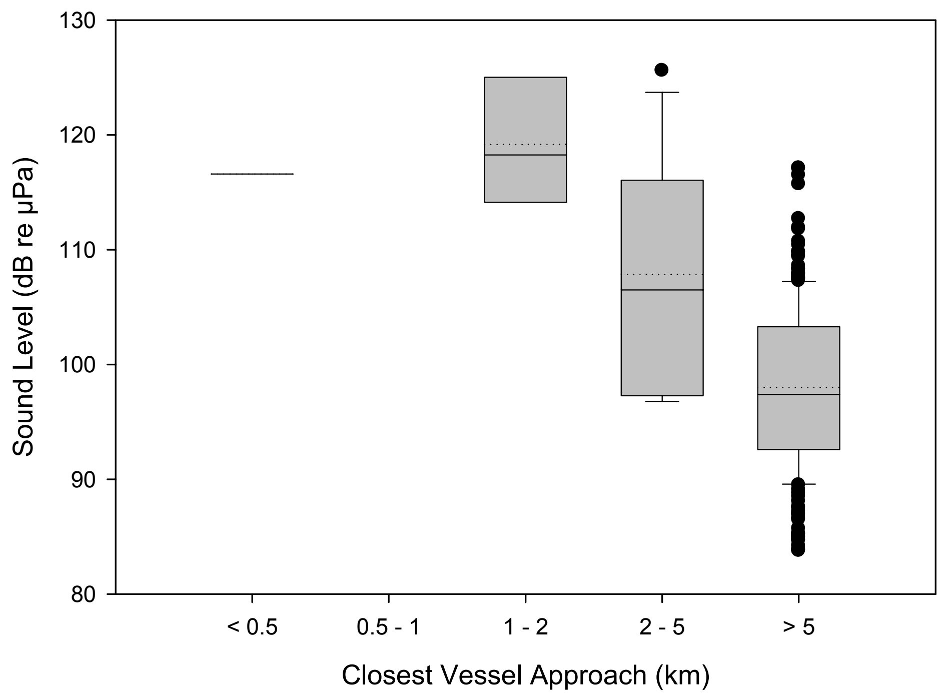


Figure 6. Box-plots representing the distribution of received underwater sound at the prediction point closest to a monitored whale as a function of distance of closest approach (to whale) during (A) movement and (B) focal behavioral observations. Only one focal observation occurred when vessels were < 0.5 km, therefore a single line represents this data point. Display as in Figure 5.

Impact Models

After accounting for natural variation in the response variables, sound level and vessel activity variables (Table 2) were applied to the model for each response one at a time. Results are presented in Table 5. Four of 65 impact tests were significant at the $\alpha = 0.05$ level. Nine of 65 tests were significant at the $\alpha = 0.10$ level. Each of these significant tests are described separately below.

Negative coefficients (Table 5) for the closest approach factor indicated that whale speed significantly increased when vessels (primarily research Zodiacs conducting photo-id work) were within 0.5 km of the animal relative to those times when vessels were further away. Based on the model fit, the speed of the whale was predicted to be 0.21 to 1.19 km/h higher during all whale activities when the vessel was within 0.5 km compared to an approach distances greater than 0.5 km. However, estimated effects of closest approach distance on speed of whale movement were not linear. The slowest observed speeds occurred when a vessel was within 0.5 km to 1.0 km of a whale. Speeds increased to approximately a constant level when vessels were greater than 1.0 km from the whale, and speed was highest when vessels were within 0.5 km.

Both increased sound level at the nearest grid point location to a whale's location and increased sound level + shoreward variables were significantly correlated with increased gray whale distance from shore. The model predicted whales would be 7 m to 119 m farther offshore for every 10 dB (re 1 μPa) increase in anthropogenic sound. The residual plots for distance from shore, however, show a bias towards overpredicting distance from shore for distances greater than 1.5 km. When anthropogenic sound equaled 85 dB (= 5th percentile), whales on the 10 m depth contour were predicted to have an average offshore distance of 1.15 km. When anthropogenic sound increased to 116 dB (= 95th percentile), whales on that part of the 10 m depth contour were predicted to have an average offshore distance of 1.35 km, a difference of 0.2 km.

Figure 7 plots the relationship of sound levels as a function of animal distance from shore, which does not demonstrate a clear linear relationship, but also does not adequately represent the multivariate analyses because other covariates are in the model and all bins were included without weighting data to observations (see "Methods" and residual plots in Appendix B).

To further explore distance from shore of whales in relation to sound levels, we examined scan sampling data that are more likely to a representative estimate of whales from shore during the scan. Furthermore, we examined nearby (< 5km) vessel presence separated compared to when no vessels (i.e. no vessel < 5 km from the whale) were in the area. These results are illustrated in Appendix C and compared to similar plots of movement bins. These plots do not represent a discernable pattern between sound levels and distance from shore. However, they do illustrate some of the highest sound levels of exposure where those in relation to nearshore research vessel activity as opposed to construction activity at the CGBS site. Although these preliminary results are not a fair comparison to the multivariate model and scan information lacked observations of higher exposure in comparison to track bins, it does illustrate that observational data that occurred at higher exposure levels are likely to be due to nearshore vessels since some of the highest sound levels are those at greater distances from the CGBS site when research vessels were within 5 km of the whales.

Unfortunately, we could not distinguish between sounds produced by the CGBS and those produced by both small and large research vessels in the sound records. Our best proxy for whether a small boat or large boat was producing sound near the whale was distance of closest approach. Small Zodiac vessels conducting photo-id research were generally the only vessels to approach within 0.5 km of a whale. Box plots of offshore distance (Figure 8) revealed little difference across all closest approach categories, making it difficult to identify a primary sound source potentially responsible for moving whales further offshore.

Dive time decreased significantly with increasing distance from the CGBS location, even after accounting for the estimated decrease in dive time in shallow water that came into the model during Phase I of model selection. In other words, if two dives were made in the same water depth, the dive closer to the CGBS would be estimated to be longer in duration.

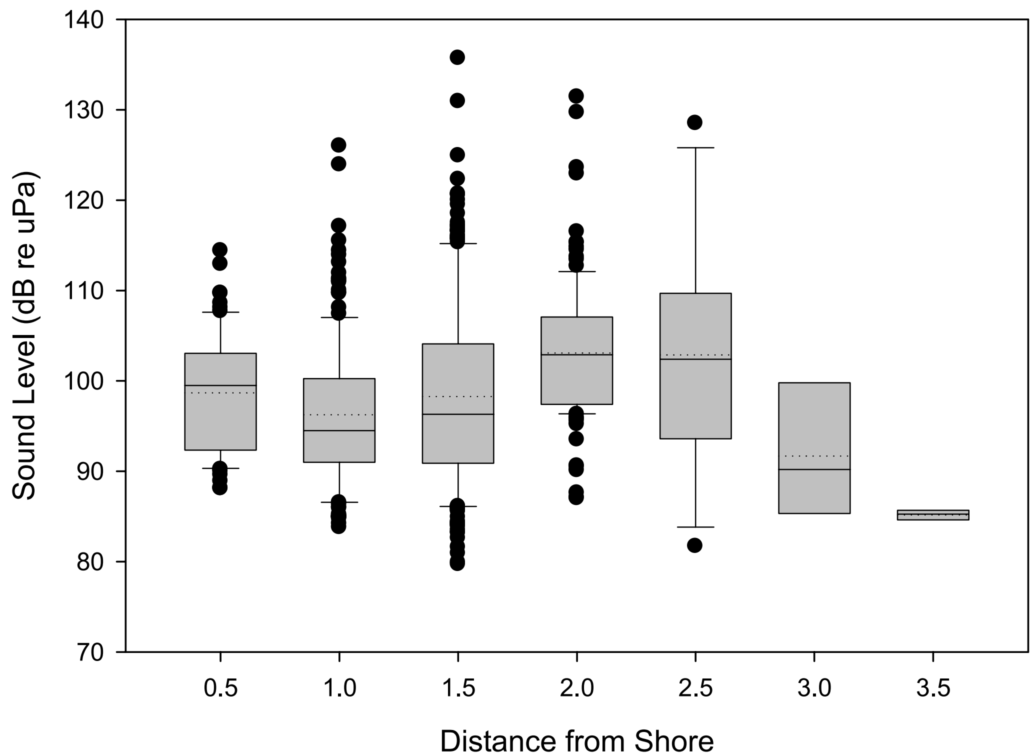


Figure 7. Box-plots of received underwater sound levels at the closest prediction point to a western gray whale as a function of distance of the whale from shore. Display as in Figure 5.

At a significance level of 0.10, the dive-surface blow rate increased as the number of vessels increased, potentially indicating a more active state. Surface time of whales increased as sound level increased; however, this trend was non-significant when shoreward distance was taken into account. An increase in mean vector length (i.e. animals moving in a more constant direction) was associated with vessels approaching within 0.5 km. Distance from shore increased as the number of vessels increased.

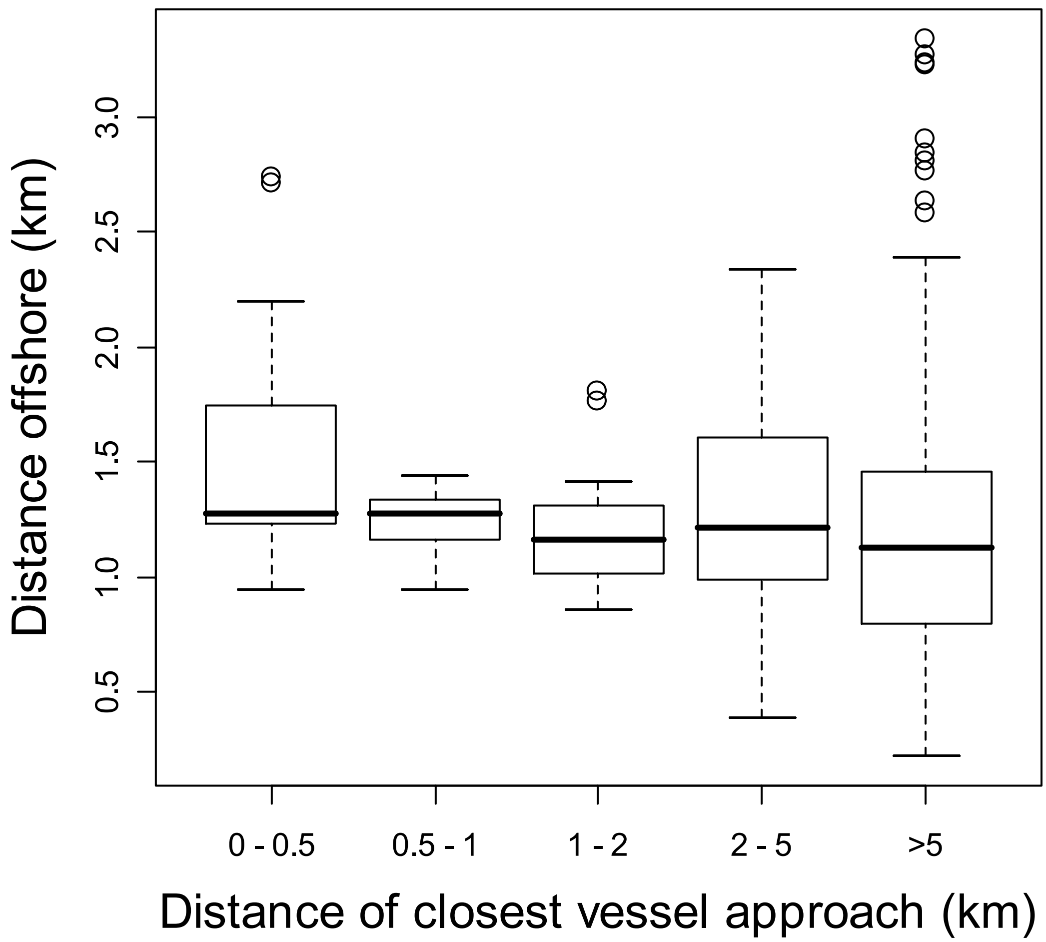


Figure 8. Box-plots of offshore distance of western gray whales as a function of closest vessel approach. Display as in Figure 5 except that the mean is not displayed.

Table 5. Results of impact tests on western gray whale (A) movement and (B) respiration behavioral responses. Significant levels were computed by block permutation (Appendix B) after accounting for natural variation. 'Estimate' is the estimated coefficient. 'Low limit' and 'High limit' are lower and upper endpoints of a 95% confidence interval computed by block permutation. 'P-value' is the block permutation test of the effect. Tests with significance levels < 0.1 are highlighted. Tests with significance levels < 0.05 are highlighted and italicized.

A) Movement responses:

	Response											
	Speed				Distance from Shore				Linearity			
Industrial Variable	Estimate	Low limit	High limit	P-value	Estimate	Low limit	High limit	P-value	Estimate	Low limit	High limit	P-value
Closest Vessel (Reference = < 0.5 km)												
0.5 - 1.0 km	-0.70111	-1.18848	-0.21081	***0.021***	-0.22879	-0.63368	0.13253	0.133	-0.96261	-2.77614	0.93510	0.405
1.0 - 2.0 km	-0.38021	-0.70269	-0.01223		-0.18361	-0.49320	0.10271		-1.43322	-2.73946	0.02685	
2.0 - 5.0 km	-0.33344	-0.59248	-0.03001		-0.05383	-0.29958	0.17483		-0.74512	-1.92685	0.61558	
> 5.0 km	-0.46645	-0.72302	-0.11255		-0.24041	-0.47223	0.02775		-0.74539	-1.81800	0.49095	
Number of vessels	0.06926	-0.03173	0.15380	0.170	0.07559	-0.01456	0.15383	0.087	-0.05761	-0.40851	0.26277	0.744
CGBS Distance	-0.00416	-0.00960	0.00101	0.147	-0.01557	-0.02120	-0.01308	0.100	0.01074	-0.00700	0.02773	0.229
Sound Level	0.00260	-0.00408	0.00867	0.456	0.00637	0.00070	0.01193	***0.035***	-0.01581	-0.03569	0.00346	0.126
Sound Level	0.00273	-0.00319	0.00880	0.217	0.00648	0.00088	0.01180	***0.032***	-0.01583	-0.03659	0.00535	0.310
Shoreward Distance	-0.14697	-0.28819	0.00936		-0.09873	-0.25112	0.03441		0.02017	-0.55698	0.61347	

	Response											
	Range				Reorientation Rate				Acceleration			
Industrial Variable	Estimate	Low limit	High limit	P-value	Estimate	Low limit	High limit	P-value	Estimate	Low limit	High limit	P-value
Closest Vessel (Reference = < 0.5 km)												
0.5 - 1.0 km	-0.83533	-1.62782	0.00824	0.121	1.86401	-17.11115	19.99306	0.489	0.11000	-0.10769	0.30795	0.518
1.0 - 2.0 km	-0.54916	-1.13192	0.09400		6.21241	-7.82300	20.48647		-0.00960	-0.19645	0.17561	
2.0 - 5.0 km	-0.43727	-0.92005	0.09268		5.40728	-6.22962	18.24852		0.08213	-0.10702	0.28087	
> 5.0 km	-0.60451	-1.11863	-0.08548		0.86700	-9.42008	13.27157		0.07135	-0.09563	0.23426	
Number of vessels	0.09352	-0.07700	0.26845	0.270	2.16047	-1.50838	5.51355	0.184	-0.00128	-0.03354	0.02880	0.950
CGBS Distance	-0.00544	-0.01463	0.00438	0.253	-0.10066	-0.31068	0.08284	0.284	0.00072	-0.00085	0.00211	0.392
Sound Level	0.00218	-0.00904	0.01220	0.693	0.10610	-0.12366	0.34993	0.331	-0.00018	-0.00199	0.00145	0.856
Sound Level	0.00235	-0.00844	0.01285	0.406	0.10550	-0.12425	0.33395	0.517	-0.00020	-0.00205	0.00164	0.885

Industrial Variable	Estimate	Low limit	High limit	P-value	Estimate	Low limit	High limit	P-value	Estimate	Low limit	High limit	P-value
Shoreward Distance	-0.20133	-0.46057	0.06237			-4.64149	6.75146			-0.05582	0.08809	

	Response			
	Mean Vector Length			
Industrial Variable	Estimate	Low limit	High limit	P-value
Closest Vessel (Reference = < 0.5 km)				
	-1.29674	-3.30393	0.50702	0.097
	-1.69199	-3.23186	-0.11707	
	-1.77592	-3.06305	-0.45631	
	-1.12382	-2.33763	0.09402	
Number of vessels	-0.17397	-0.57162	0.21204	0.358
CGBS Distance	0.01234	-0.00816	0.03305	0.257
Sound Level	-0.01195	-0.03508	0.01036	0.332
Sound Level	-0.01186	-0.03587	0.01169	0.515
	-0.10015	-0.72724	0.51992	

B) Respiration responses:

	Response											
	Dive time				Number of Surfacings				Blow Interval			
Industrial Variable	Estimate	Low limit	High limit	P-value	Estimate	Low limit	High limit	P-value	Estimate	Low limit	High limit	P-value
Closet Vessel (Reference = < 0.5 km)												
0.5 - 1.0 km	NA	NA	NA	0.231	NA	NA	NA	0.367	NA	NA	NA	0.167
1.0 - 2.0 km	0.70647	-0.20356	1.55239		0.31290	-1.40011	1.85928		-0.14341	-0.53662	0.45047	
2.0 - 5.0 km	0.23633	-0.58826	0.93967		-0.25890	-1.83970	1.31057		-0.13541	-0.43317	0.39784	
> 5.0 km	0.28912	-0.46058	0.94861		-0.27283	-1.77116	1.15288		-0.00410	-0.27381	0.54419	
Number of vessels	0.06941	-0.14393	0.26833	0.627	0.11423	-0.19040	0.41237	0.489	-0.07273	-0.17124	0.01738	0.169
CGBS Distance	-0.01135	-0.02091	-0.00235	***0.016***	0.00546	-0.00768	0.01879	0.443	0.00018	-0.00373	0.00417	0.936

Sound Level	0.00897	-0.00194	0.01952	0.128	0.01413	-0.00206	0.02959	0.103	-0.00294	-0.00772	0.00207	0.271
Sound Level	0.00966	-0.00173	0.02030	0.174	0.01405	-0.00132	0.02879	0.202	-0.00304	-0.00794	0.00193	0.309
Shoreward Distance	-0.18524	-0.56947	0.13636		0.09132	-0.31527	0.55640		0.07284	-0.06613	0.21446	

	Response											
	Dive-Surface Blow Rate				Surface Blow Rate				Surface Time			
Industrial Variable	Estimate	Low limit	High limit	P-value	Estimate	Low limit	High limit	P-value	Estimate	Low limit	High limit	P-value
Closest Vessel (Reference = < 0.5 km)												
0.5 - 1.0 km	NA	NA	NA	0.270	NA	NA	NA	0.127	NA	NA	NA	0.539
1.0 - 2.0 km	-0.08779	-1.07507	0.96173		0.07654	-1.02000	1.01863		0.15833	-3.10048	2.58565	
2.0 - 5.0 km	-0.27764	-1.16553	0.67551		0.30670	-0.64732	1.17891		-0.79243	-4.01774	1.36805	
> 5.0 km	-0.43142	-1.24138	0.49673		-0.04308	-0.92239	0.72630		-0.44233	-3.53738	1.54391	
Number of vessels	0.17934	-0.03010	0.35839	0.097	0.13741	-0.08776	0.36218	0.226	-0.01879	-0.50497	0.49468	0.953
CGBS Distance	0.00682	-0.00157	0.01566	0.146	-0.00073	-0.01038	0.00777	0.870	-0.00011	-0.02143	0.02169	0.986
Sound Level	0.00637	-0.00362	0.01670	0.264	0.00222	-0.00979	0.01416	0.730	0.02291	-0.00149	0.04910	0.090
Sound Level	0.00640	-0.00387	0.01664	0.485	0.00237	-0.00948	0.01364	0.543	0.02269	-0.00046	0.05051	0.198
Shoreward Distance	-0.05616	-0.34531	0.22427		-0.16733	-0.47956	0.13604		0.23170	-0.54066	0.92877	

Discussion

Natural variation

Gray whale behavioral state (i.e., feeding, traveling, feeding/traveling, and mixed) included in the pool of natural explanatory variables was an important predictor in 62% (8 of 13) of all models. This was consistent with a previous univariate analyses that examined differences among activities (see Gailey *et al.* 2006, Table 10). Since behavioral states are generally characterized by observing a animal's movement and respiration patterns during its brief periods at the surface, the behavioral characterization may be influenced by the very response variables that we are attempting to explain. Consequently, we acknowledge that some (unquantified) circularity may have been introduced by including behavioral state as a natural predictor for responses such as speed, reorientation rate, and linearity. We included behavioral state of the animal as a predictor, despite some circularity in its definition, because these activities were "normal" for western gray whales and we were interested in explaining aberrant behavior associated with anthropogenic variables. Several previous studies also demonstrated that whales may respond differently depending on current behavioral activity. For example, resting whales are more likely to be disturbed by sounds than animals engaged in foraging and social activity (NRC 2003, Richardson *et al.* 1995).

We reasoned *a priori* that if behavioral states eventually entered a regression model, the model would be immediately interpretable and anthropogenic activity, if also included as a strong predictor, would explain aberrant behavior within the behavioral state categories. For example, anthropogenic sound could potentially explain why a particular whale's speed was higher than that normally observed for traveling whales. In other words, we could estimate that traveling whales normally do so at a speed of *X* km/h, then in effect check for association between higher (or lower) speeds for traveling whales in the presence of higher (or lower) anthropogenic sound levels. We are confident that the amount of circularity present in behavioral states is small and does not diminish our ability to detect industrial effects. Empirical evidence supports this position because a substantial amount of variation remained in the models when behavioral states were included.

The models examining natural or environmental variables identified several that explained a large amount of variation in western gray whale behavior and movement patterns. For one, gray whales in deeper water increased their dive durations. Past observations of western gray whales indicated that they dive approximately 1.0 minute shorter, on average, than eastern gray whales. It was hypothesized that this difference in dive time was due to the very shallow nature of the western gray whale study area (for example, Weller *et al.* 1999). Indeed, Würsig *et al.* (1986) found a general increase in eastern gray whale dive time in deeper (> 20 m) water, which agrees with the dive time model presented here. In other words, there may be no large difference in “natural” dive times between the two populations when they are generally non-social during foraging and traveling. We have no information on western gray whales during winter mating and calving season when they are more social.

Distance from station was included as an explanatory variable in the model for blows/surfacing. It is unclear why the number of blows/surfacing would have increased with increasing distance from the observation platform since we might at first expect to miss more blows from animals further away from shore, despite the fact that we corrected for offshore observational bias by weighting each observation by the number of bins. Since about one-half of whales observed were generally in deeper water, this relationship may again be due to a general depth-related surface/dive pattern, and may thus represent a real phenomenon. Indeed, Würsig *et al.* (1986) found that whales in deeper water also had slightly longer surface times and concomitant greater numbers of blows/surfacing. Perhaps whales that dive longer in deeper water require more breaths at the surface to offset increased oxygen needs (Wartzok 2002). If this is the reason why blows/surfacing increase with distance from station, it is not likely to be a strong association because water depth was not identified as a strong predictor of blows/surfacing.

Increased wind speed was associated with dive-surface blow rate. Since the dive-surface blow rate is akin to “panting”, or breathing quickly when individuals are more energetic, and represents our best proxy for activity level, this increase potentially indicates an increase in activity as sea state increases. The phenomenon of increased surface activity with increased sea state has been noted before in many whales, but the link with respiration rate has not been clear in most cases (Whitehead 1985).

The majority of the environmental, temporal, and spatial variables that were considered were not found to be associated with any of the models. Whale response variables did not show differences among the six observation stations, indicating similar movement and respiration patterns among different behavioral states along the entire 66 km of observation region in the nearshore feeding area. This does not mean, however, that the frequency of occurrence of these activities is not spatially different. Rather, it is likely that when animals engage in feeding, for example, they feed in a similar manner along the observational range. Temporal factors such as time of day, date, and season were also not found to explain a significant amount of variance in any of the natural models. This study only applies to the period that whales are on their feeding ground, and periods of arrival and the onset of migration are not likely to be represented in the data set, and therefore in these analyses.

Potential Impact on Western Gray Whales

With the exception of distance from shore, the multivariate analyses indicate no statistically significant relationship between sound levels and the behavioral movement and respiration response variables. There were relatively few observations above 120 dB re µPa levels where previous studies have observed behavioral reactions of gray whales to continuous sound exposure (Figure 4; Malme *et al.* 1986). This is likely a result of the noise mitigation strategy employed to minimize sound exposure levels above 120 dB within the Piltun feeding area during industrial/construction operations, and actively mitigating and monitoring sound levels in the field (SEIC 2005, Rutenko 2006). Distance from shore was, however, significantly associated with both sound level and sound level + shoreward distance variables. Coefficients in the offshore distance model indicated that as the sound exposure levels increased, gray whales were predicted to be further from shore. As stated earlier, the model fit for distances greater than 1.5 km overpredicts this effect compared with actual data. The same pattern of response (i.e. movements further offshore) was observed in our 2001 analyses that evaluated western gray whale behaviors in relation to a geophysical seismic exploration survey (Gailey *et al.* submitted). It is known from other studies that both marine and land mammals can feel "hemmed in" by a perceived danger, and will often edge away by moving into more open, unfettered space where presumably they can run, or swim, in any direction (Würsig and Evans 2001).

As gray whales approached regions of construction activity further offshore, they were more likely to be exposed to increasing sound levels. This pattern of increased sound levels in relation to offshore distance (Figure 7) is, however, not apparent in relation to the whales monitored in the present study. For example, some of the highest observed sound levels were those at a 1.5 km distance from shore at 2nd Station, which is approximately 15 km north of the PA-B site, as opposed to the two closer locations (1st Station and South Station) to the construction activity. This is likely due to the number of research vessels that may actually be inshore of the gray whale being monitored, and a response to further distance from shore could be a result of avoidance of even higher sound levels as a vessel approaches (see Appendix C). At this time, however, it is not clear whether the whales' general response to sound is to move further from shore largely due to the proximity of vessels in their area, whether the response is a general one to sound, or it is an artifact of sound levels tending to be higher further from shore.

Our inability to ascertain the sound source (i.e. nearshore research vessels versus offshore construction activity) limits our interpretations. For one, whales may respond differently depending on the activity of the sound source and its current location in relation to the whale. For example, Tyack and Clark (1998) found differences in avoidance by migrating eastern gray whales when the sound source was placed in the migratory path compared to when it was placed seaward of the migratory pathway. Comparatively, sounds generated by research vessels operating inside their primary feeding grounds may not have the same impacts on gray whale movement and behavior as sounds generated from the offshore CGBS construction site. Therefore, lumping all sounds levels regardless of the source may hinder our ability to detect important reactions from a particular sound source or activity. Furthermore, other baleen whales, such as fin and right whales, have been noticed to tolerate stationary sound sources, such as the CGBS construction site, more than sound sources that are moving towards them (Watkins 1986). These factors suggest that the whales may have reacted more strongly to research vessels than to the construction activity that occurred in 2005. For this reason, we plotted scan sampling information and separated data when vessels were present (< 5km) from those when no vessels were present (see Appendix C).

Gray whales have been noted to respond to nearby (generally less than 0.5 km) vessel activity (see Moore and Clark 2002). As a vessel approached within 0.5 km of a whale, an animal's speed significantly increased relative to when vessels were at greater distance. Such a response to vessels can be obvious in the field. We have tracked a whale for several hours before a vessel approached, and have observed an obvious change in behavior and movement when the vessel was nearby. The whale then usually reverts back to its previous behavior when the vessel moves out of the area. Such short-term behavioral responses in activity and movement are arguably not biologically significant, but may become truly disruptive if the disturbance becomes frequent enough. We have observed groups of individuals being separated or "split" as a reaction to vessel activity. Such social disruption, described numerous times before in whales and dolphins exposed to human-related activity, may become biologically significant (Richardson and Würsig 1995) if it occurs repeatedly and disrupts feeding or social activities, particularly if it results in separation of a mother and nursing calf.

Swartz and Jones (1979) found that vessels moving erratically or at high speeds in Baja California breeding lagoons sometimes caused eastern gray whales to swim rapidly away, but there was little or no whale response to slow-moving or anchored vessels. Similarly, Bogoslovskaya *et al.* (1981) found that on summer feeding grounds, eastern gray whales fled when Soviet catcher vessels approached within 350-550 m, but generally paid no attention to vessels at distances > 550m. It is possible that the whales were sensitized to catcher boats due to previous negative experiences with them. In our experience, vessels that tend to stay on one course at a relatively constant speed with little erratic movement induced relatively minor shifts in behavior unless they were within several hundred meters of the whale. Smaller (research) vessels that approach whales often change gray whale behavior at least in the short term, especially if these small vessels are driven with rapid shifts in engine speeds and with rapid changes in direction of approach towards whales.

Distance to the CGBS was significantly associated with dive time. This relationship is likely due to a complex relationship between water depth, dive time and distance to the CGBS. Whales that were observed closer to shore are generally in shallower water as opposed to the whales closest to the offshore CGBS construction site, and shallower dives were associated with decreased depths.

A few general caveats apply to the results of this study. The methodologies employed here collected data on a single individual or group at a time. Ideally, we would have collected information on a random sample of individuals from the population, but this was impossible without unique identifiers and without real-time tracking of all individuals of the population. If the cumulative set of individuals we observed were not representative of the entire population, our results will not apply to the entire population. However, we have no reason to believe that the individuals we observed were non-representative of the entire population, and in fact we believe we collected information on a large fraction of the individuals in the population. A second caveat is that we weighted the number of bins to the individual in an attempt to account for inclusion bias issues (see methods) and to minimize pseudoreplication. We argue that weighting to the individual would likely produce a more accurate result than simply ignoring these biases, but we acknowledge that weighting itself is unlikely to be perfect.

Biological Significance

Any behavioral change obviously has associated costs to the individuals since the energy invested to avoid the disturbance could have been invested towards other needs, such as acquiring more food. In addition, repetitive exposure to a stimulus that elicits behavioral response has the potential of causing cumulative stress or could have the reverse effect of habituation. Even short-term responses that have the potential to separate mom-calf pairs could become biologically significant (NRC 2003). However, it is extremely difficult to attribute the immediate response of an individual to parameters such as decreased foraging efficiency, growth, survivability, reproductive successes, etc., since the result occurs on a much larger temporal and spatial scale than the immediate response alone (NRC 2005). In addition, unknown physiological factors such as stress and cumulative exposure may lead to biological significant effects. The objective of this study, however, was to examine if construction sound or proximity of vessels that elicit behavioral response potentially affected the animals ability to feed, which is the primary activity of this endangered population during this time period. Since behavioral response indicators are likely the first signs of disturbance that could lead to diminished feeding activity, we believe this is a good management approach towards protecting this population.

Conceptual models, such as the Population Consequences of Acoustic Disturbance (PCAD) model, are important tools that provide structure to evaluate potential consequences of anthropogenic activity in regards to biologically significant affects (Figure 9). Although some understanding of relationships between sound and behavioral responses of baleen whale populations exists; with the expectation of loss of life, the relationship between these associations and their potential affects on life history functions and vital rates are largely unknown for marine mammal populations (NRC 2005). In other words, there is no claim that PCAD is a predictive mathematical tool, but rather a tool to help structure evaluations of biological significance.

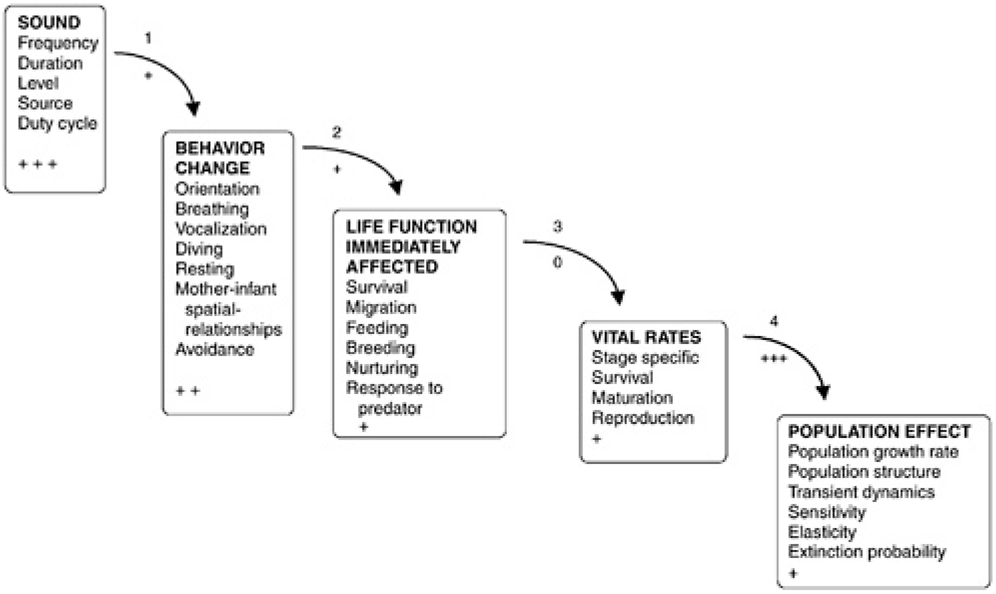


Figure 9. The conceptual Population Consequences of Acoustic Disturbance model that illustrates stages required to relate acoustic disturbances to effects on marine mammal populations. Taken from NRC(2005).

As stated in NRC (2005), "*the presence of anthropogenic sound sources could have minimal effects on a healthy population that can relocate with minimal effort or could be devastating to a small population that is living on the edge of its capabilities to survive*". This highlights a clear need to be conservative in data interpretation of what may or may not be biologically significant for western gray whales. Recognition of this issue is important and one of the primary factors that emphasis has been placed on understanding the natural behavior of western gray whales and monitoring their activity during construction operations. Our focus here has been on the behavioral effects and it is important to recognize that animals will tolerate small disturbances assuming they do not reach a threshold that affects feeding, compromises survival, reproduction of the animals, etc.

It is incumbent on us to outline areas that need further exploration and address the limitations of our current analyses relative to potentially biologically significant effects of anthropogenic activities. For example, the potential effects of construction activity that were reported to have the highest sound levels (i.e. CGBS tow-in and placement) are not represented here and, therefore, the impacts of these activities are unknown. These "loud" activity periods were, however, relatively short in duration (2 days) and overall resulted in an increase of about 3 dB in the southern part of our observation area. Unfortunately, abundance and distributional information have not been fully analyzed in relation to sound levels and/or vessel activities to further examine potential disturbances. Our preliminary plots suggest that higher sound level exposure were more associated with research vessels compared with sound levels from construction-related activity. As stated earlier, we assume our data to be representative of the population and includes mother calf pairs. The ability to determine significant effects could potentially be compromised to some degree by the idea that not all individuals in the population are likely to be affected or react in the same manner, and any association of response may under-represent certain age, sex, and groups of individuals (for example, mom-calf pairs, yearlings, skinny whales, etc.).

We believe our approach here represents initial insights that examine potential subtle behavioral changes of western gray whales to anthropogenic activities. This report highlights that potential impacts are not only those associated with industrial construction operations, but also the number of vessels operating on the western gray whale feeding grounds. Sound levels and exposure were not statistically associated spatially (Figure B.1, Table B.1, Appendix B), indicating that nearshore research vessels operating in the area substantially contribute to the overall sound exposure budget of western gray whales on their feeding grounds. Figure A.3 (Appendix A) graphically illustrates the exposure of sound in relation to nearshore vessel movement in the northern region of our study area. However, sounds generated by vessels continually operating in one area with relatively longer durations of exposure may elicit a different response to vessels traveling through the nearshore area with shorter durations of exposure. Continual exposure of sound may lead to habituation of certain individuals, but also could lead to abandonment of frequently exposed areas by other more sensitive individuals to anthropogenic activity (for example, Bejder *et al.* 2006).

An offshore movement or shift in distribution of gray whales may place individuals in less optimal foraging areas (Fadeev 2006) and potentially expose certain individuals, such as calves, to increased risk of predation. However, offshore movement noted in this study was not particularly large (and potentially an artifact of overprediction of the model) and gray whales were continually observed to be feeding throughout the observation area.

Our results indicate that the primary behavioral effects observed were those associated with research vessel activity compared with sounds generated from construction operations at the CGBS site. This suggests that if sound reached a level that elicited a movement response, the effect was likely to be of short duration due to the nature of the research vessel movements as they typically spend a relatively short time period remaining in one localized area. Observations of mom-calf pairs within the vicinity of the construction site during the two construction phases observed (Anchor installation and scour protection) suggest they were continuing to utilize the feeding habitat around the construction site. Furthermore, we did not observe obvious indicators of disturbance from the construction activity monitored in the field that would have raised concerns of impact to individuals or to the western gray whale population.

Conclusions

From our analyses of western gray whale behavior in nearshore areas off the northeastern coast of Sakhalin Island during construction of the CGBS, we draw the following conclusions:

(1) There were no detectable effects of increased anthropogenic underwater sounds on whale speed, acceleration, linearity, mean vector length, reorientation rate, ranging index, blow interval, surface time, dive time, number of blows per surfacing, surface blow rate, and dive-surface blow rate. As in all studies that fail to reject a null hypothesis of no impact, anthropogenic sound could be affecting these behavioral parameters but our data set did not contain enough information to conclusively identify that the effect existed.

(2) Model predictions indicated that whales would be slightly further offshore as anthropogenic sound increased. We were unable to distinguish between sound generated by the CBGS construction vessels and the nearshore research vessels that were operating within the feeding grounds and therefore were unable to directly test the effects of sound from the CGBS construction activities alone, statistically. The residuals of the model illustrated a pattern of overprediction beyond 1.5 km. In addition, our interpretation of the results and preliminary analyses of scan data suggests potential affects are more likely attributed to nearshore research vessel activity as opposed to construction operations. .

(3) Consistent with previous studies, gray whale swim speed increased during all whale activities when vessels approached to within 0.5 km of a whale indicating a particular sensitivity to close vessel approaches.

(4) Dive time decreased with increased distance from the CGBS installation. We hypothesize that this decreased dive time is associated in some complicated way with water depth, and is not likely to be a direct effect of the CGBS installation.

Recommendations

Vessels that are operating in the feeding area can produce a significant amount of noise for a very short period of time. Furthermore, as the number of vessels increases, the cumulative effect of sound exposure to the animals is likely to increase as well. There should be a conscious effort to minimize both the time that vessels are within the feeding grounds of western gray whales, and the number of simultaneous vessels operating within one localized area. Since vessels need to occur in this region to properly monitor the population status, benthic community, sound levels produced, etc., it is perhaps more practical to implement the latter recommendation of fewer vessels in a localized region.

We also believe that it is important that any vessel operating within the nearshore feeding area should keep detailed records of vessel movements and activities. This will not only improve the accuracy of determining received sound levels and evaluating potential impacts on the behavior of western gray whales, but also provide a record of the extent and duration of such activity for the entire season. Furthermore, it is important to evaluate the level of vessel activity on both a temporal and spatial scale.

To advance our understanding of natural variation of western gray whale behavior, it would be beneficial to evaluate other environmental parameters that were not considered here. Swell heights examined in this study were field estimates and more accurate acquisition of these data would be beneficial. In addition, swell period, swell direction, wave height, wave period, and wave direction were all examined in the multivariate analyses conducted in 2001, but were unavailable for this study.

Perhaps the most important consideration to account for natural variation in gray whale movement and respiration patterns on their feeding grounds is prey availability and concentration. Data collected on gray whale prey distribution and biomass in the western gray whale feeding grounds identifies relationships between food availability and shifts in whale distribution on the feeding grounds (Fadeev 2005, 2006).

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Appendix A: Acoustic Energy Estimation to Whale Locations

Estimation Method

To evaluate potential effects of sound on western gray whale behavior, the broadband (20 Hz–15 kHz) underwater acoustic levels were estimated in the nearshore feeding area on a semi-regular grid (Figure A.1). The grid points were arranged in equally spaced rows following the profile of the shoreline at 1 km separation starting 1 km offshore in the E-W direction and at 1 km separation in the N-S direction. The grid extended from about 5 km north of the northernmost observation station to about 5 km south of the southernmost station. The maximum distance of a whale's location to any given grid point was 0.7 km.

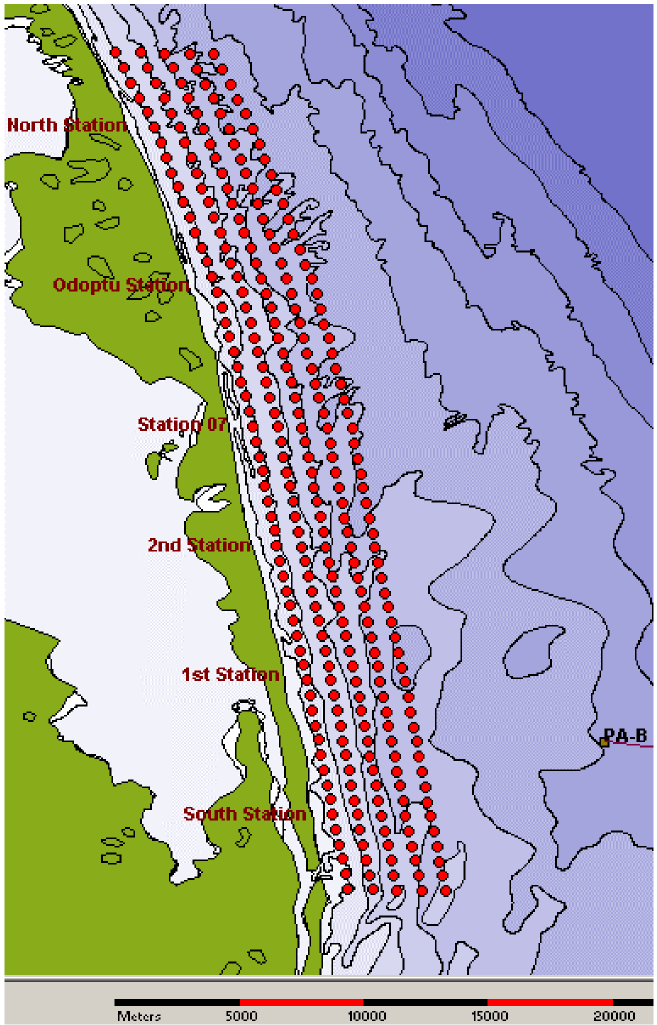


Figure A.1. Arrangement of sound prediction grid points along the Piltun coastline. Depth contours are marked in 5 m increments, starting at 5 m depth closest to shore.

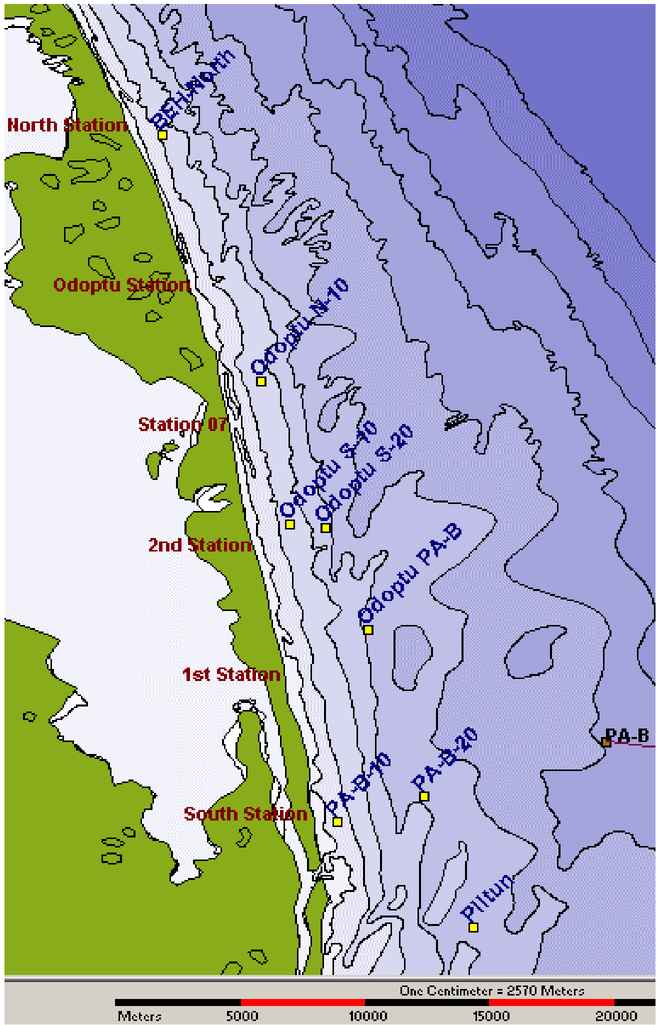
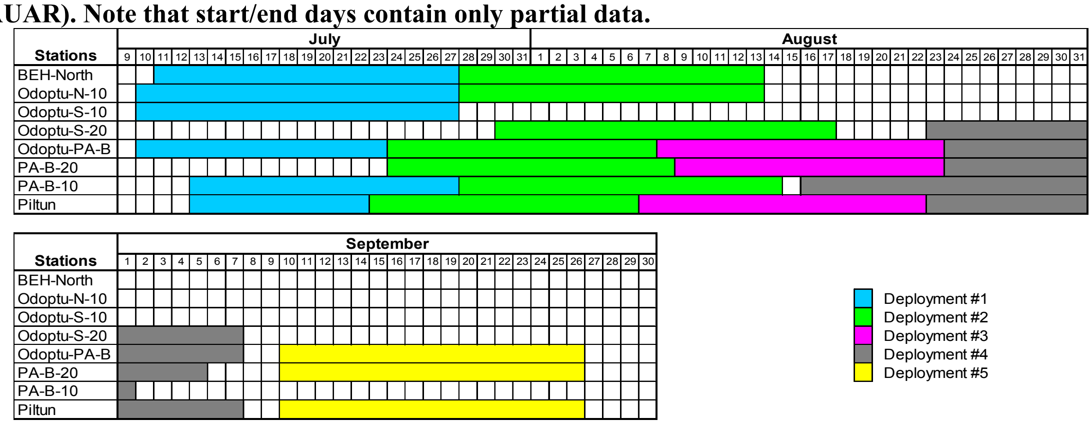


Figure A.2. Nominal locations of the AUAR acoustic recording units.

One-minute broadband acoustic energy levels at the locations shown in Figure A.2 were provided by the acoustics team of the Pacific Oceanological Institute from continuous measurements made by eight autonomous underwater acoustic recorders, or AUARs, deployed during the period of offshore construction activity at the PA-B platform site. The AUARs were serviced on an approximately biweekly schedule to replace the batteries and to download the data. Servicing caused relatively short (of the order of several hours) periods of downtime in their operation. Some of the AUARs were deployed for only part of the season. Table A.11 provides an overview of the periods of data availability for all the AUARs used in this study, with the proviso that the start and end days of each period would only have partial coverage due to the redeployment downtime.

Table A.1. Periods when data were available from autonomous underwater acoustic recorders (AUAR). Note that start/end days contain only partial data.



Estimation of acoustic energy at grid points was based on a hybrid approach that combined numerical modeling of sound level variations over the region of interest with the direct acoustic measurements at the AUAR locations. To model sound distribution, we assumed a composite acoustic field given by the superposition of a quasi-static sound footprint from the activities at the PA-B site and a time-evolving field from nearshore sound sources. The primary known nearshore sound source was the research vessel used for a variety of tasks that included deployment, retrieval, and maintenance of the AUARs. The assumption of a composite acoustic field as described above is justified by the fact that the sound field from PA-B activities originates relatively far offshore (some 8 km) from the region of interest, so that the displacement of construction vessels operating in the vicinity of the platform site would have only a minor modifying effect on the sound distribution in the grid area, whereas the acoustic footprint from the research vessel operating mostly within the grid is greatly influenced by its location. Furthermore, these two components can be considered the dominating contributors to the acoustic “topography” of the alongshore region – the platform construction activity because of its intensity at the origin, the nearshore research-related activity because of its proximity;

other sources would most of the time introduce only lesser variations. The modeled sound distribution was used to generate a "difference matrix" relating acoustic level at each grid point to that measured at the nearest available AUAR at any given time. The resulting values are therefore time-dependent both because of variation in the sound level at each AUAR and because of changes in noise distribution due primarily, in the shorter term, to the moving location of the research vessel.

As a preparatory step, we modeled received sound levels at all grid points and AUAR locations from the activities at the PA-B site through full runs of the underwater acoustic propagation model MONM (Hannay and Racca, 2005). The scenario definitions were the same as those used in pre-season noise modeling for station-keeping anchor installation, CGBS positioning and lowering, and scour protection deposit (in practice, gray whale observations took place only during the first and last of these phases). We applied the same "measurement referenced" adjustments to these values as those that had been applied post-season to the original acoustic maps on the basis of average AUAR readings. The corresponding modeling of the received sound levels from the research vessel (either the *Academik Lavrent'ev* or its sister ship the *Academik Oparin* later in the season) posed a challenge because of the very large number of instances associated with following the motion of the vessel through the area at one-minute time resolution. Since performing full MONM runs at each source location would have been prohibitive in terms of computational load, we resorted to characterizing acoustic transmission loss for the research vessel's sound signature by running the model for a number of representative source locations and propagation directions within the region of interest. We found that a simplified broadband attenuation law of 17 log R provided an adequate fit to the modeled transmission loss curves over the range of distances relevant to this analysis; this formula was used in the time-dependent acoustic footprint estimation process to be described below. In the absence of more specific data the sound from the research vessel was always modeled using a source level measured under transit conditions at normal speed; this would obviously overestimate the sound contribution in cases where the vessel may have been moving under low power or stationary. The impact on the overall estimation accuracy is nonetheless moderated by the fact that the modeling yields only a modifying term, based on the difference between model estimate and data from the nearest AUAR, so that even if the modeled level from the vessel is excessive the end result would be "clamped down" by the actual measurement. The method described here should provide a more realistic portrayal of the relative topology of the noise level than a mere interpolation (or worse, extrapolation) of the levels at grid locations some distance from the AUARs. Later we present an example of full-grid estimation as well as a form of self-validation of the approach (as opposed to a true validation based on independent measurements at grid points) that support this conclusion.

Having prepared the numerical modeling foundation, we estimated acoustic energy over the grid in one-minute increments for all time intervals over which individual whales had been followed by the behavioral observation team. The processing sequence for each grid point and time step was conducted as follows:

1) Look up the modeled sound level at the grid point for the ongoing operational scenario at PA-B at the time of interest (such as anchor installation or scour protection deposit), for a receiver modeling depth of 10m.
2) Determine the position of the vessels *Lavrent'ev* or *Oparin* at the desired time from GPS track records; compute the range R to the grid point and estimate the received sound level from the vessel at that point using an approximate Transmission Loss formula (level = source level - 17 log R).
3) Sum the sound levels from 1) and 2) to obtain total modeled sound level at the grid point.
4) Identify the nearest AUAR to the grid point for which a data value was available at the time of interest. If a data value from the nearest AUAR was not available, select next-nearest AUAR– up to a specified maximum range.
5) Compute the modeled sound level at the selected AUAR location by going through steps 1) to 3) above, for a receiver modeling depth at the seafloor.
6) Retrieve the measured one-minute acoustic energy at the selected AUAR at the time of interest.

7) Compute the dB difference between modeled sound levels at the grid point and at the selected AUAR.
8) Adjust by that dB difference the energy measurement at the selected AUAR to obtain estimated acoustic energy at the grid point.

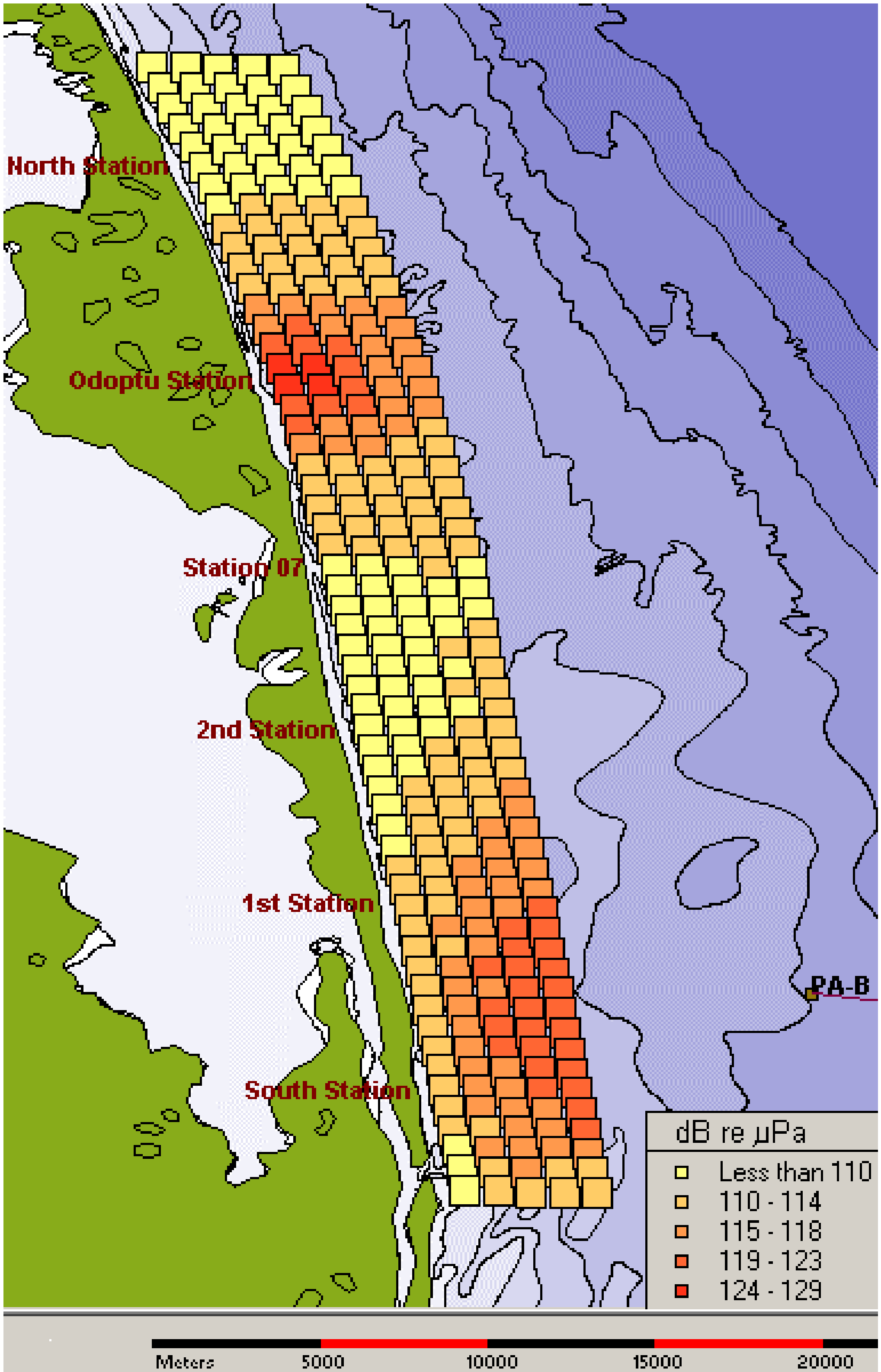

North Station
Odoptu Station
Station 07
2nd Station
1st Station
South Station
PA-B
dB re µPa
Less than 110
110 - 114
115 - 118
119 - 123
124 - 129
Meters
5000
10000
15000
20000

Figure A.3. Sound levels estimated over the grid for an observation interval. Depth contours as in Figure A.2.

The final step in generating sound level results for analytical purposes was to sum one-minute acoustic energy values over the temporal bin width that was used for behavioral observations. This bin width being 10.5 minutes, the total was computed by adding ten consecutive one-minute acoustic energy values in Pa^2-s plus one-half the subsequent value; the result was then converted to an average sound level in dB re µPa. A sample full-grid sound level distribution map for an observation interval is shown graphically in Figure A.3. In this illustration, it is easy to identify in the southern region of the grid the outer fringe of the acoustic footprint from the construction activity at the PA-B site (in this case the installation of station keeping anchors) and further north, opposite the Odoptu Station, the noise from the *Academik Lavrent'ev* operating within a few kilometers from shore. It is particularly evident in this case that any estimation of the grid levels based solely on the AUAR values, without additional information about the noise distribution derived from modeling, is bound to miss entirely the local maximum caused by the vessel since the footprint from the latter does not extend significantly to the nearest measurement locations. This gives a qualitative argument in support of the method used; we shall provide below a more quantitative assessment of its level of accuracy.

Self-validation

In the absence of direct sound level measurements at locations other than the AUAR sites, a self-validation of the method was performed using the AUAR values as reference. This was done by generating, through the same approach described above, sound level estimates at individual AUAR locations on the basis of values at the remaining sites. The measurements at the target AUARs then allow a comparative assessment of the accuracy of the estimation, subject to some considerations to be discussed further on. Figure A.4 shows the distribution of the discrepancy between estimated and measured sound level values based on consecutive 10-minute averaging intervals for the southern group of AUARs – the ones most exposed to the noise footprint of the CGBS construction. The set of intervals used in this comparison includes all available data for these AUARs over the anchor installation phase of the operation; error distribution histograms are shown both for each individual AUAR and for the complete dataset. The 95th percentile of the overall error distribution is bounded between -4 dB and +5 dB, indicating a slight bias of the method toward overestimating.

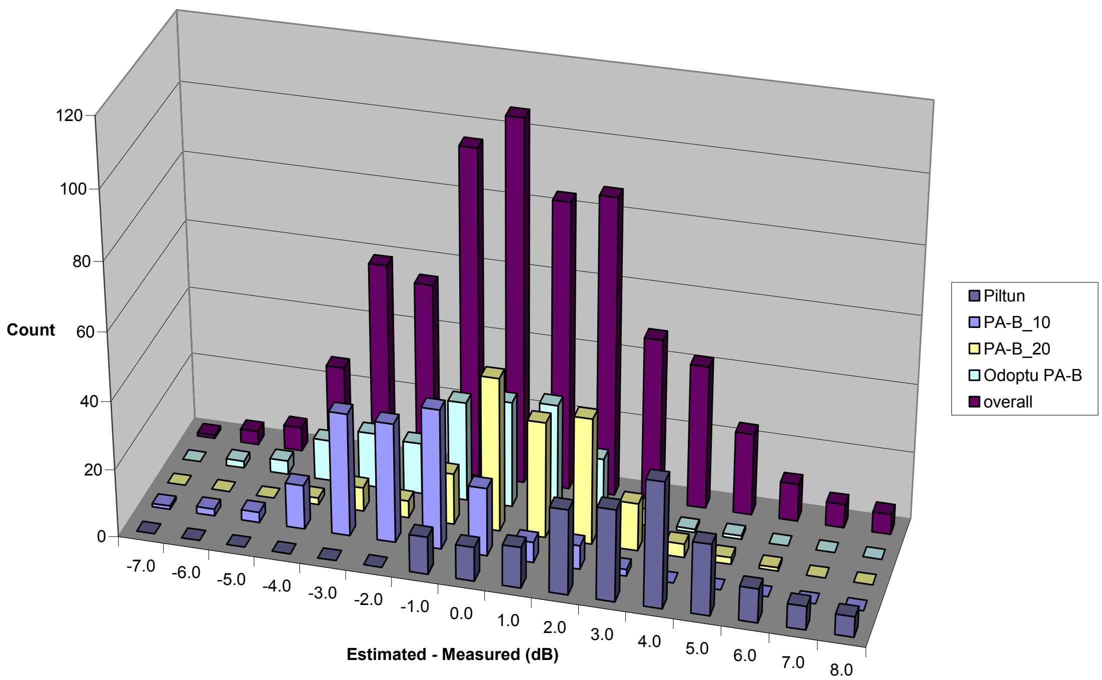


Figure A.4. Distribution of the discrepancy between estimated and measured sound level values at several AUAR locations, for individual stations and overall. Positive discrepancy values indicate that the estimate exceeds the measured value.

In actual use the level estimations by the hybrid model-measurement approach should surpass in accuracy the results of the self-validation presented. The argument for this claim rests on the fact that in performing the cross-comparison of estimated vs. measured values at the AUAR locations we are forced to disregard the very measurement on which estimates in that neighborhood would normally be based, namely the level at the target AUAR itself. In the actual estimation of the grid values the nearest AUAR to the target location is always used to provide the base level; this would greatly reduce the potential for deviation that arises from using a more distant reference.

Appendix B: Statistical Details

This appendix contains additional results and details on the multivariate models used to analyze whale behavior surrounding the CGBS installation in 2005 by providing 1) correlation and box-plot information, 2) additional justification for the model fitting method, and 3) residuals of the final model. Textural descriptions are given first, followed by all tables and figures.

Correlations and Boxplots Among Explanatory Variables

Table B.1 and Figures B.1 – B.9 show relationships between natural and industrial covariates. Table B.1 contains estimated correlations between continuous natural covariates and industrial covariates. Figures B.1 – B.9 contain box and whisker plots of categorical covariates and industrial covariates. High correlation (generally, > 60%) or definite patterns in the box and whisker plots between one or more natural covariates and one or more industrial covariates would imply confounding effects, and interpretation would be difficult in those cases. No such correlations were found in the data with the exception between distance to CGBS and station, as noted in the main text.

Justification and Logic Behind Two Phased Model Selection

Our primary objective was to test for association between behavior variables and anthropogenic behavior variables. We chose a two phased model selection approach to satisfy this objective for the following reasons: 1) because it is a common approach in other settings (e.g., human clinical trials that test for association between use of a new drug and disease incidence rate), 2) because natural variation in behavior could be masking an important impact effect, and 3) because our 2001 univariate analysis showed no impact, but our 2001 multivariate regression analysis showed some impacts once natural variation was taken into account.

In reality, inclusion of the natural variables in behavioral models could have either helped or hindered our ability to detect industrial effects, and it was impossible to know which the case was *a priori*. If natural variables were correlated with impact variables their effects were confounded. In this case, our method of fitting natural variable first would attribute variation to natural sources, when in fact it could be due to either natural or industrial effects. Conversely, high variation could have prevented detection of an impact effect unless natural variables were included to explain a large proportion of it (as was the case with our 2001 analyses). We are confident that natural and impact effects are not confounded, and that natural variables are not masking impact effects, because computed correlations and box-plots (Table B.1 and Figures B.1 – B.9) would have revealed high correlation if it were present.

The main alternative method of model selection we considered involved placing all variables (both natural and impact) into a single pool of variables and utilizing some variable selection procedure (e.g., stepwise or best subsets selection) to identify a "best" model. We chose not to implement this plan because it did not guarantee a direct test of impact variables. If industrial effects were not present, only natural variables would have come into our models under this scheme, and we would not obtain significance levels (all $> \alpha$ in this case) for the suite of impact variables. Failing to deliver direct tests of the impact variables was unsatisfactory in our opinion. This single phase plan for model fitting is also affected by correlation between natural and impact variables in the same manner as the two-phased approach.

Block Permutation Computation of Significance Levels

To account for autocorrelation among behavioral responses computed on the same track or focal animal follow, block permutation (Lahiri 2003) was employed to construct a distribution for the drop-in-sum-of-squares F statistic under the hypothesis of no impact effect. This no-impact F distribution was constructed by computing residuals from the natural variable model (i.e., that model resulting from Phase I), then assuming that individual whales were independent, randomly permuting blocks of those residuals and repeated the analysis. In other words, all residuals associated with an individual whale were viewed as a block of data, these blocks were randomly shuffled, re-associated with un-permuted explanatory variables, and the model including impact variable(s) was refitted. Randomly shuffling residuals in this way broke all associations between responses and explanatory variables, and we were sure that variation in coefficients in this case was just due to random variation (i.e., chance). All drop-in-sum-of-squares F statistics obtained over repeated shuffling of the residuals represented realizations of the F statistic under the null hypothesis of no relationship between behavioral responses and impact variables. Significance of the impact effect was the probability of exceeding the observed F statistic in this null distribution.

We employed block permutation methods to control for the effects of autocorrelation among responses. If left unaccounted for, significant positive autocorrelation would artificially inflate our F statistic and make effects appear more significant than they should. Significant negative autocorrelation would have the opposite affect. Block permutation corrected the significance level of the F test because autocorrelation in the original data was also present in the randomly permuted data. If autocorrelation either depressed or inflated the original F statistic, the same autocorrelations would have depressed or inflated all F statistics in the null distribution because autocorrelations present in the original data were present in each randomly permuted data set. In this way, computing p-values from the permutation distribution controlled autocorrelation (if present) and yielded valid probability levels under the assumption that individual whales were independent.

Experiment-wise Significance Levels

At the end of Phase II of model selection, a total of 5×13 = 65 tests were performed (Table 5 *in* Results). These tests were unadjusted for our target experiment-wise significance level. If all 65 tests were independent of one another, we would expect, over repeated applications of the entire experiment, to reject 3.25 (=0.05*65) of these 65 tests by chance alone if we conducted each at an $\alpha = 0.05$ level. If tests were independent and we were to declare "industrial activity affects behavior", without being more specific, when one or more of these 65 tests were significant, we would be almost certain (probability = $1 - (1 - 0.05)^{65} = 0.96$) to make such a declaration when no industrial effects actually existed. On the other hand, if tests were totally dependent upon one another (perfect correlation), we would actually be conducting one independent test among the 65, and the experiment-wise significance level would be 0.05.

In reality, we can only declare that the experiment-wise significance level is somewhere between $\alpha = 0.05$ and $\alpha = 0.96$ because the degree of dependence among the 65 tests is unknown. Ideally, we could remedy this situation and be more specific about the overall significance level; however, the degree of dependence among responses, the degree of dependence among impact variables, and the total effects of this dependency on the tests is very difficult to ascertain and remains unknown.

We chose straight-forward multiple testing with unadjusted individual significance levels for three reasons: 1) our conclusions were designed to be response and impact specific rather than broad statements such as “industrial activity affects behavior”, 2) an acceptable method for adjusting individual tests could not be found, and 3) the resulting liberal set of tests was acceptable from the standpoint of protecting the whale population. Our supposition that a liberal overall testing procedure was acceptable assumed that the deleterious effects of mitigating for a falsely-detected industrial impact were smaller than the deleterious effects of failing to mitigate for an undetected industrial effect. When determining management actions, we encourage readers to consider the results of the specific tests, the overall pattern of significance in our tests, and whether conclusions based on those tests are supported by other studies or the overall weight of evidence.

Residual Plots

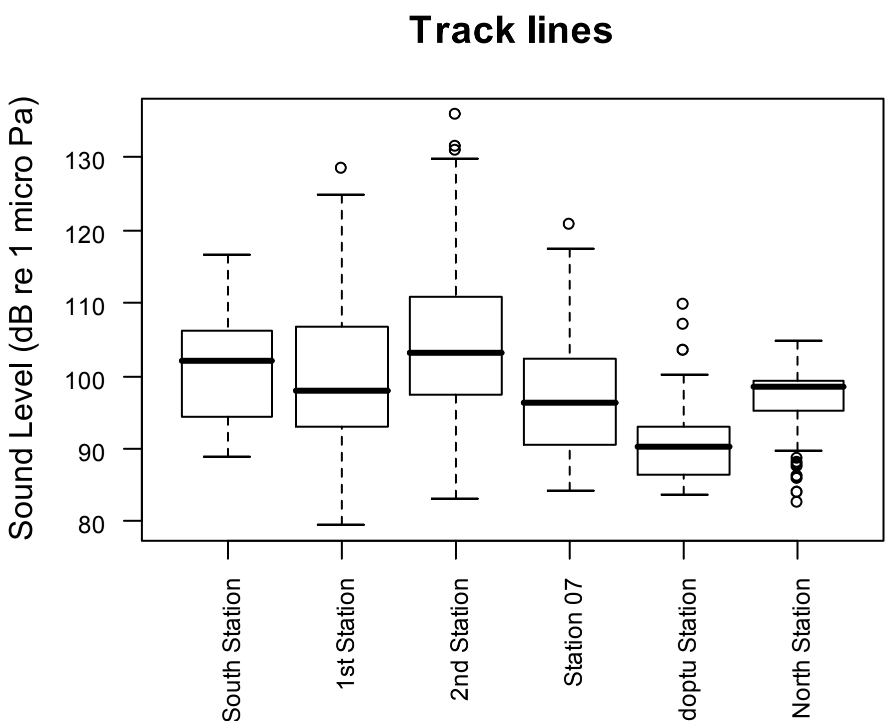
At the end of this appendix, following Figures B.1-B.9, a series of 65 residual plots appear, one for each response × industrial variable model fitted during the project. Each figure plots Studentized residuals versus fitted, or predicted, values from each model. Studentized residuals (Belsley *et al.* 1980, p. 20) are regular model residual standardized by an estimate of their variance obtained when the observation is deleted. Studentized residuals are,

$$e_i^* = \frac{e_i}{s(i)\sqrt{1-h_i}}$$

Where $e_i = y_i - \hat{y}_i$ (the regular residual), $s(i)$ = the estimated residual standard error from a model fit to a data set with the i^{th} observation deleted, and h_i is the i^{th} diagonal element of the "hat" matrix, $\mathbf{X(X'X)^{-1}X'}$. If the normality assumption holds, Studentized residuals follow a *t*-distribution with $n - p - 1$ degrees of freedom, and if the normality assumption does not hold, Studentized residuals can be expected to approximate the *t*-distribution. In these plots, the most influential 3% - 5% of all observations are highlighted. These highlighted observations have predicted values that change by a relatively large amount when they are deleted and the model refit. These residual plots reveal some individual observations that are not well predicted by the model, but no systematic over or under prediction for large or small predicted values.

Table B.1. Pearson correlation coefficients between continuous natural covariates and industrial covariates. Correlations > 0.6 highlighted. Italicized natural covariates were never considered for inclusion in the multivariate model. Their correlations are reported for information only.

		Industrial Covariates			
Data Type	Natural Covariates	CGBS Distance	Number of vessels	Sound level	Sound level + shoreward distance
Track line	Date	0.1193	0.1038	-0.0813	-0.0744
	Time of day	0.0155	0.1491	-0.0281	-0.0337
	Beaufort	0.1560	-0.0349	-0.0341	-0.0354
	visibility	-0.1442	0.0920	0.1416	0.1416
	Distance to station	-0.1271	0.0745	0.0828	0.0754
	depth	0.0206	0.0501	0.0076	-0.0028
	tide	-0.0509	-0.0522	0.0169	0.0209
	Wind speed	0.1516	-0.0390	0.1152	0.1178
	swell	0.2199	-0.0389	-0.2072	-0.2042
	Temperature	-0.1920	-0.0657	-0.0338	-0.0359
	Distance to shore	-0.3262	0.0848	0.0980	0.0891
	Time	0.1195	0.1050	-0.0815	-0.0747
	latitude	0.9743	-0.1573	-0.3037	-0.3011
	longitude	-0.9761	0.1656	0.2858	0.2822
Focal follow	Date	0.1660	0.1085	-0.0894	-0.0824
	Time of day	0.0731	0.2482	0.0533	0.0445
	Beaufort	0.1296	-0.0777	-0.1448	-0.1466
	visibility	-0.0772	-0.0366	0.2095	0.2139
	Distance to station	-0.3386	0.0177	0.1047	0.0940
	depth	-0.1886	0.1184	0.1318	0.1164
	tide	-0.0347	0.0448	-0.0067	0.0006
	Wind speed	0.4308	0.1030	0.0160	0.0244
	swell	0.1607	-0.1691	-0.2371	-0.2347
	Temperature	-0.0469	-0.2880	-0.2911	-0.2940
	Distance to shore	-0.4476	0.1080	0.1426	0.1279
	Time	0.1666	0.1105	-0.0889	-0.0821
	latitude	0.9726	-0.1217	-0.3702	-0.3649
	longitude	-0.9745	0.1364	0.3431	0.3358


Track lines
Sound Level (dB re 1 micro Pa)
80
90
100
110
120
130
South Station
1st Station
2nd Station
Station 07
doptu Station
North Station

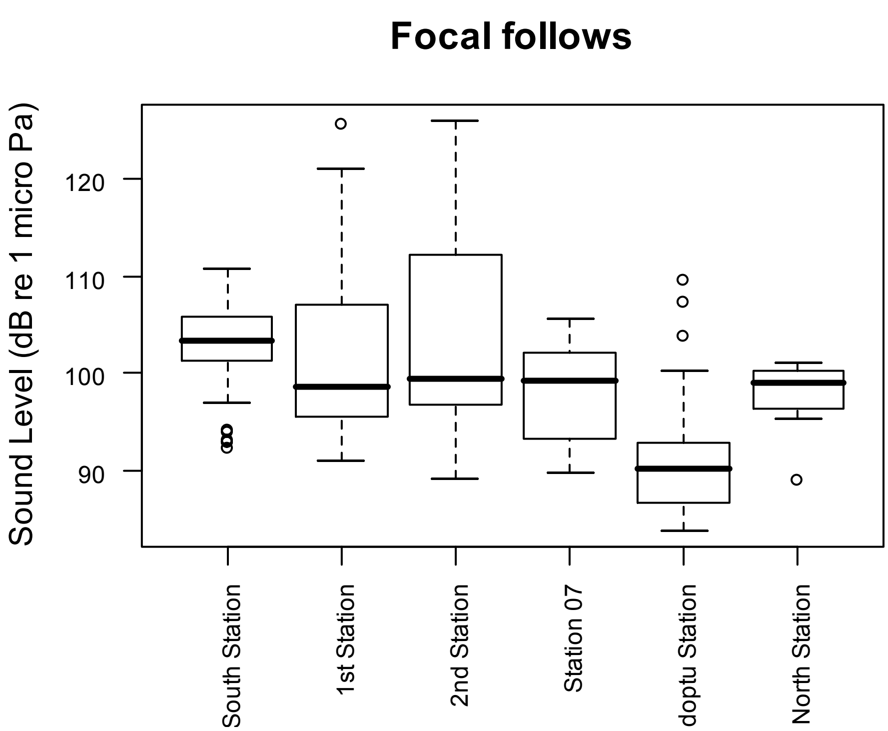
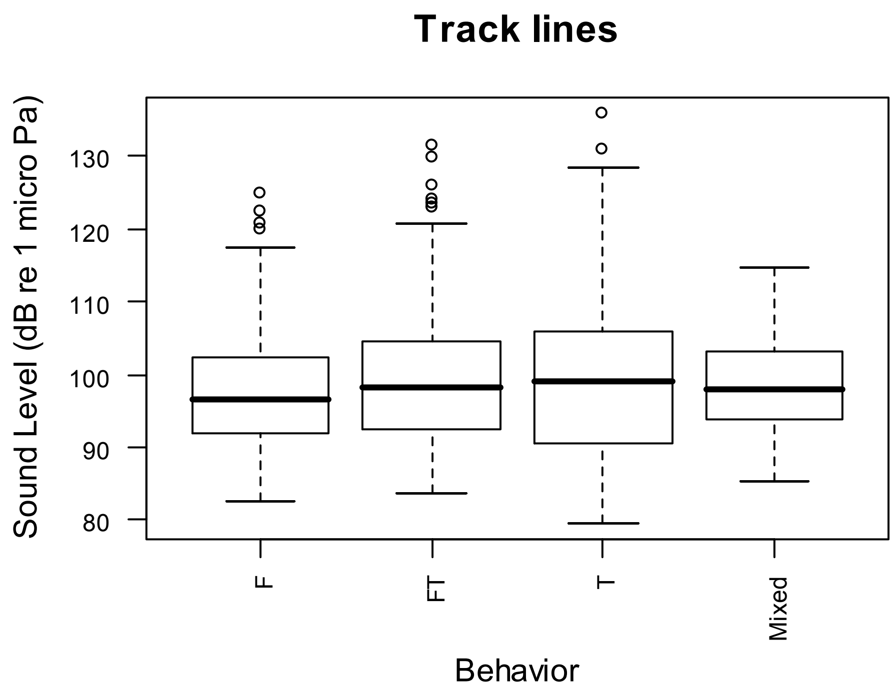

Focal follows
Sound Level (dB re 1 micro Pa)
90
100
110
120
South Station
1st Station
2nd Station
Station 07
doptu Station
North Station

Figure B.1 Box and whisker plots of sound levels by station. Upper and lower ends of box mark 75th and 25th percentiles, respectively. Dark line in the box denotes median. Whiskers extend to an observation at most 1.5*box height away from the box. Observations beyond whiskers are marked with circles.



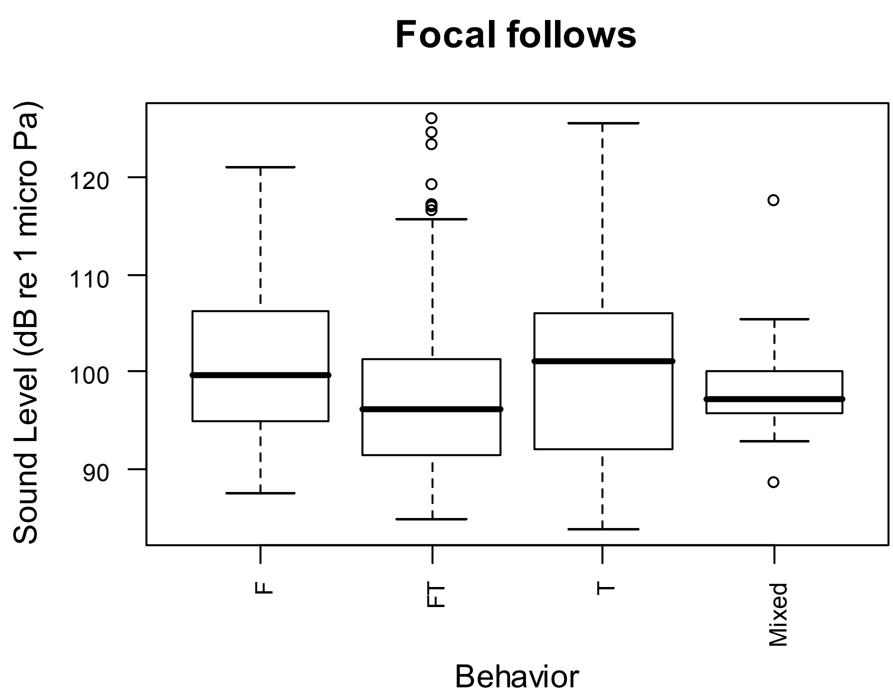
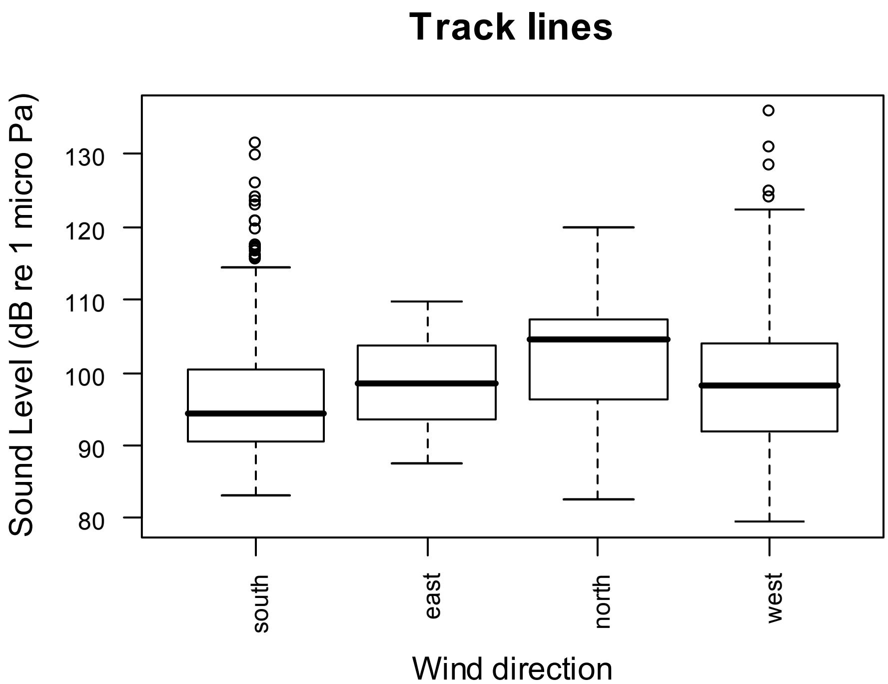


Figure B.2. Box and whisker plots of sound levels by behavior. Boxes as described in caption to Figure B.1.



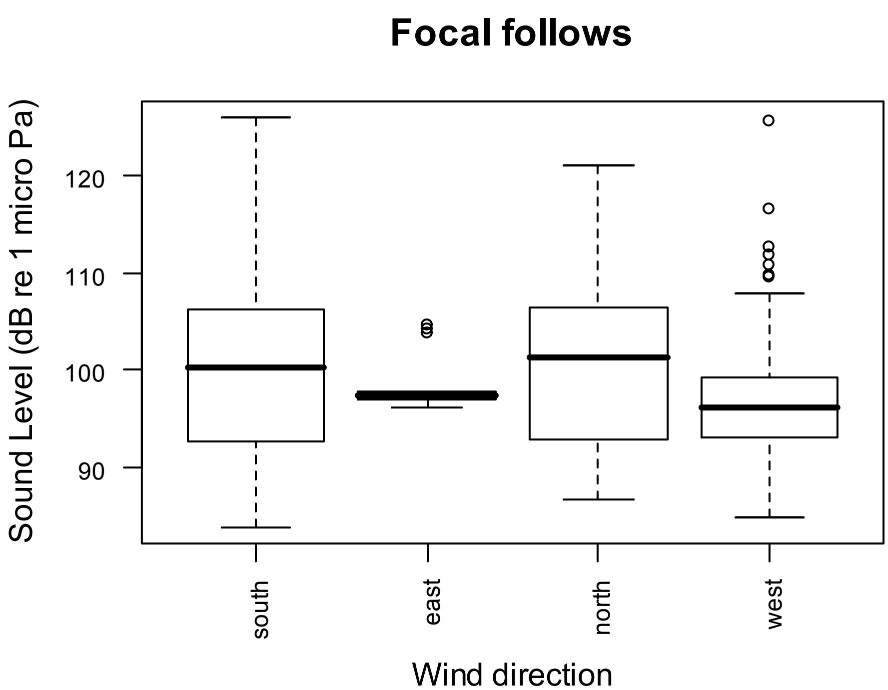
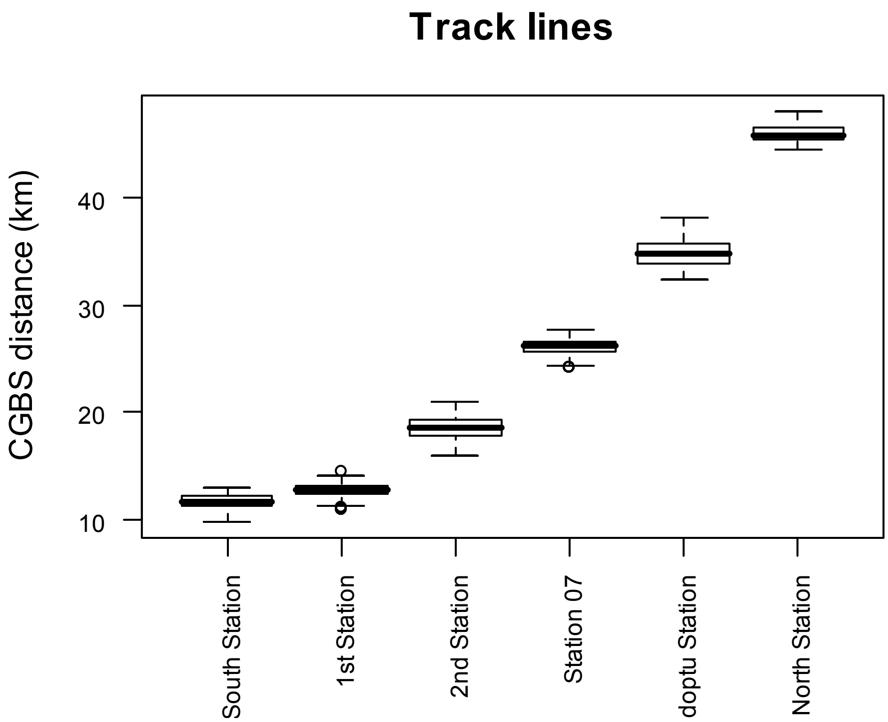


Figure B.3. Box and whisker plots of sound levels by wind direction. Boxes as described in caption to Figure B.1.



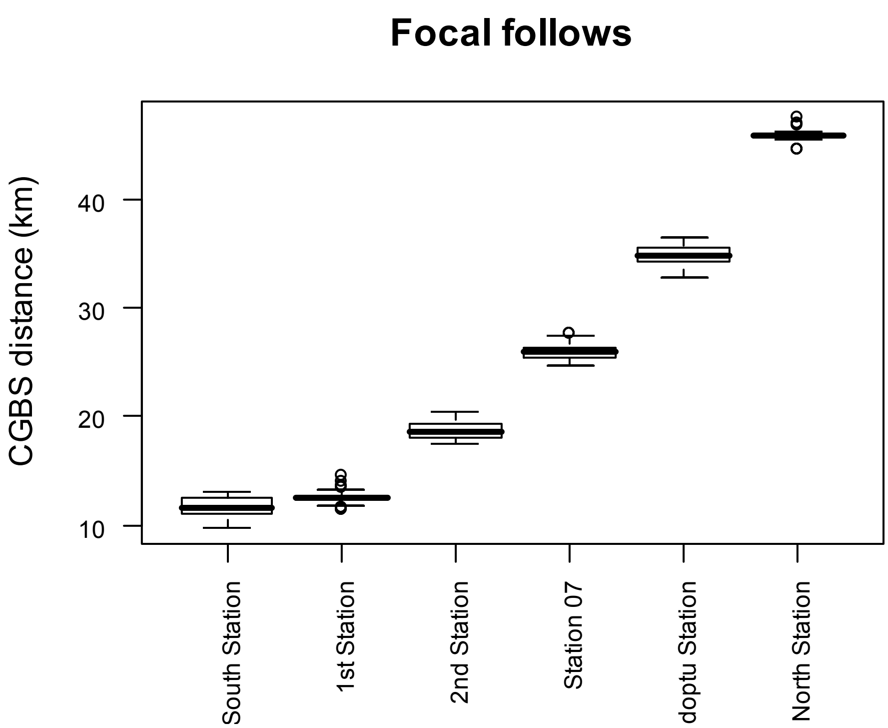
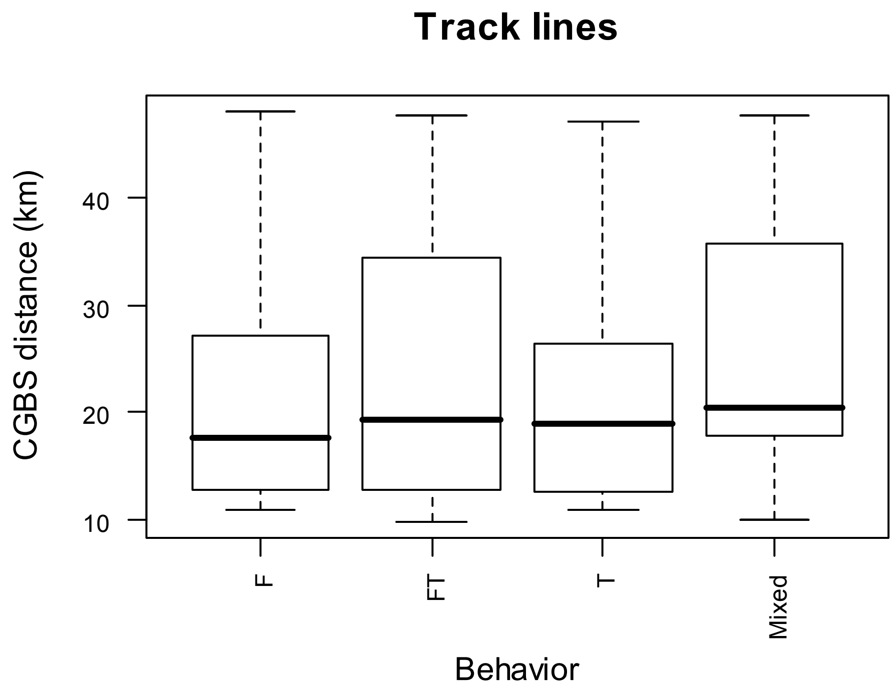


Figure B.4. Box and whisker plots of distance to the CGBS levels by station. Boxes as described in caption to Figure B.1.



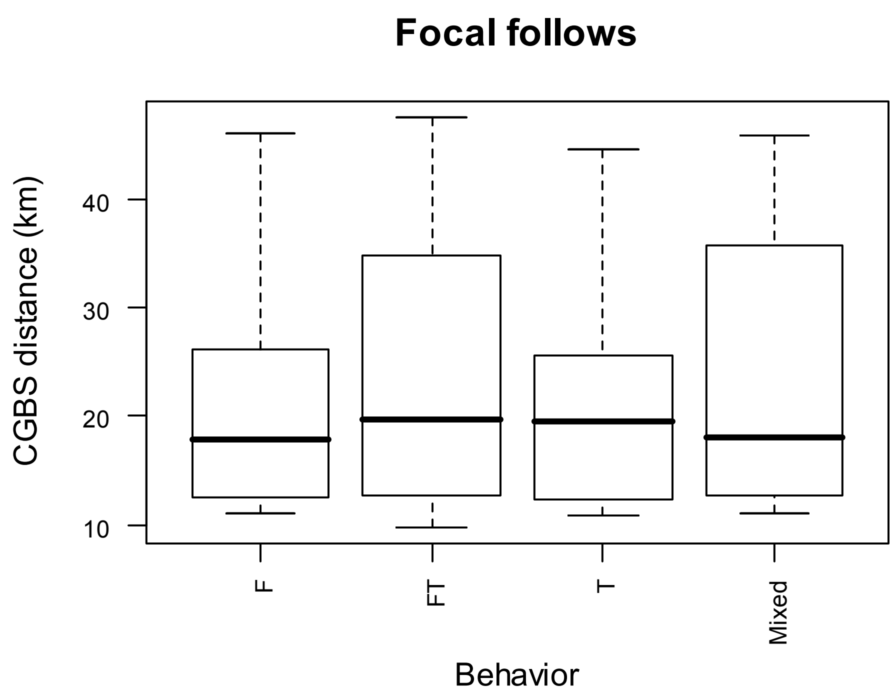
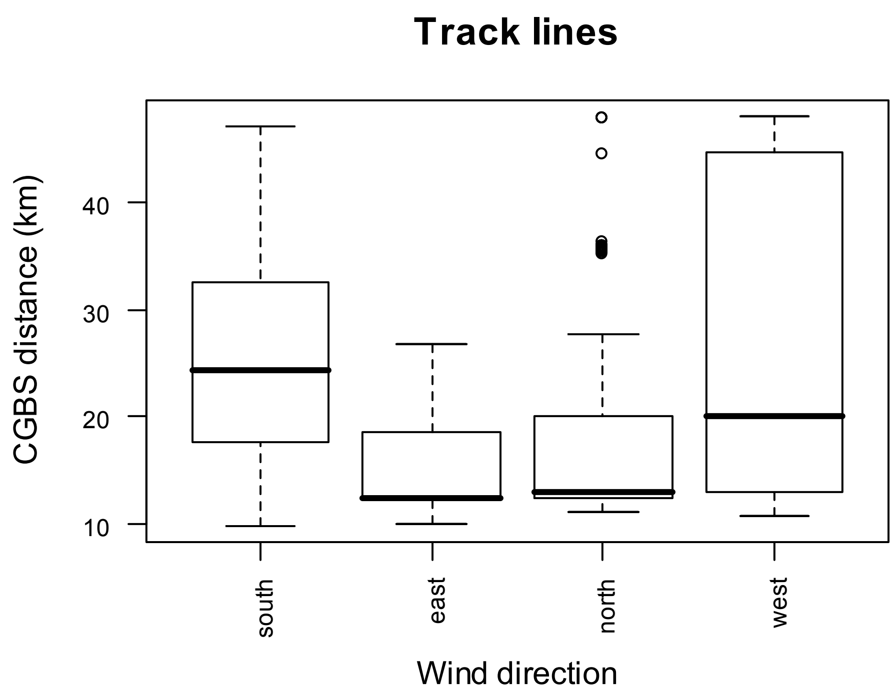


Figure B.5. Box and whisker plots of distance to the CGBS by behavior. Boxes as described in caption to Figure B.1.



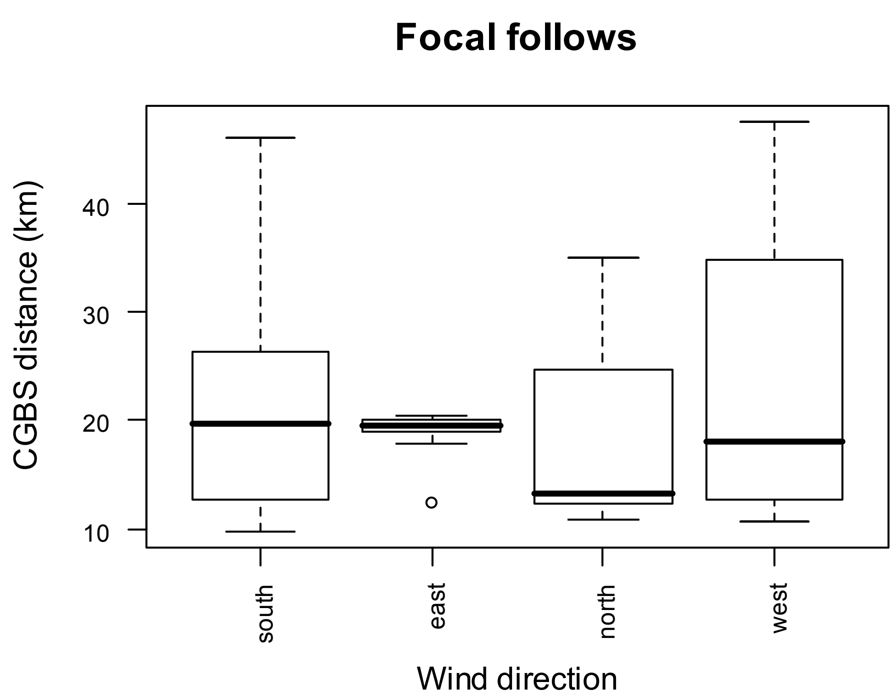
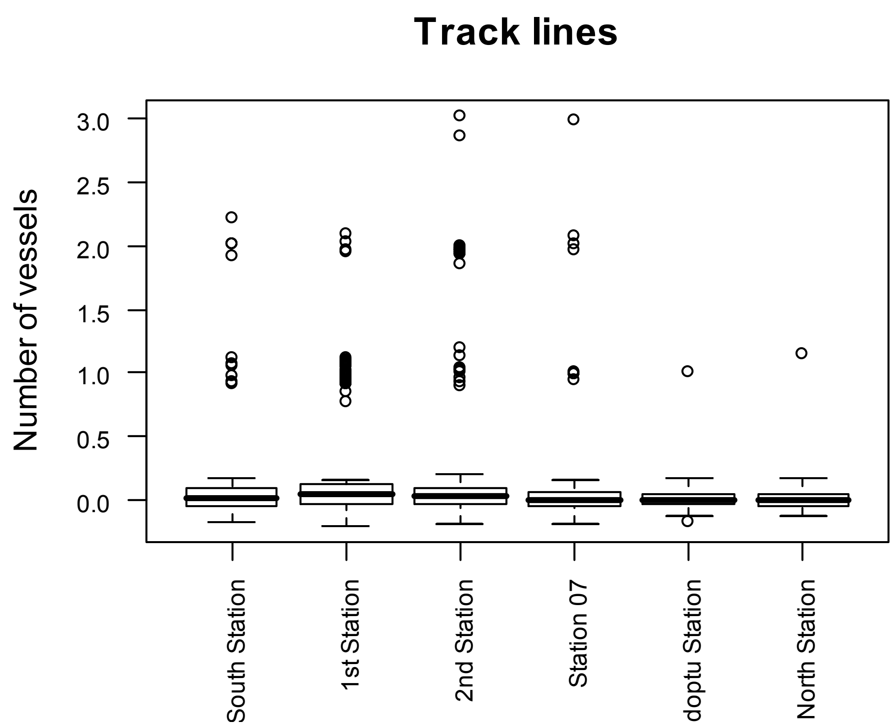


Figure B.6. Box and whisker plots of distance to the CGBS by wind direction. Boxes as described in caption to Figure B.1.



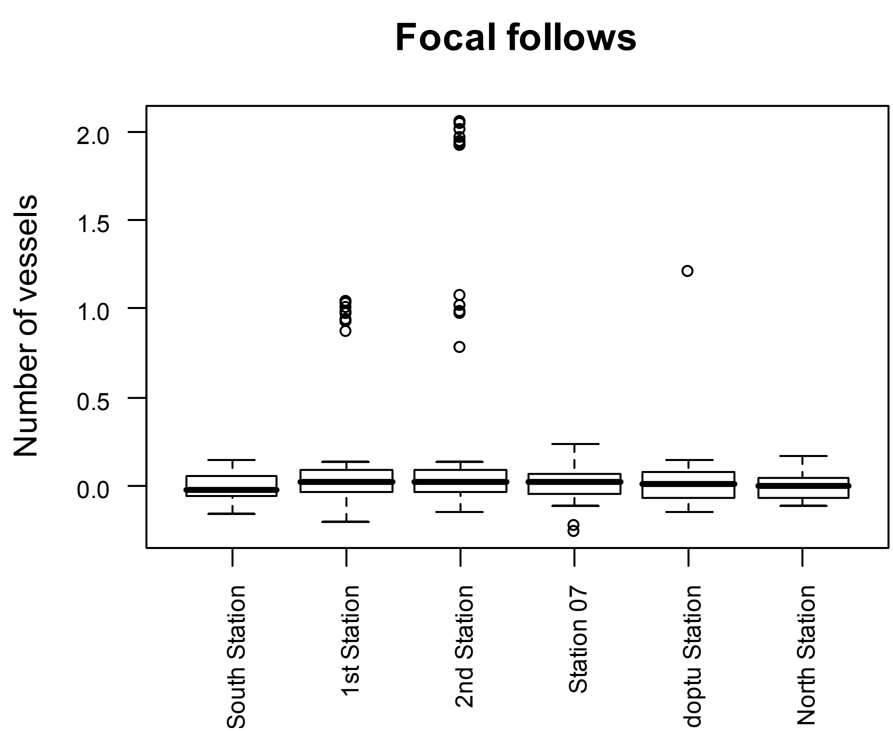
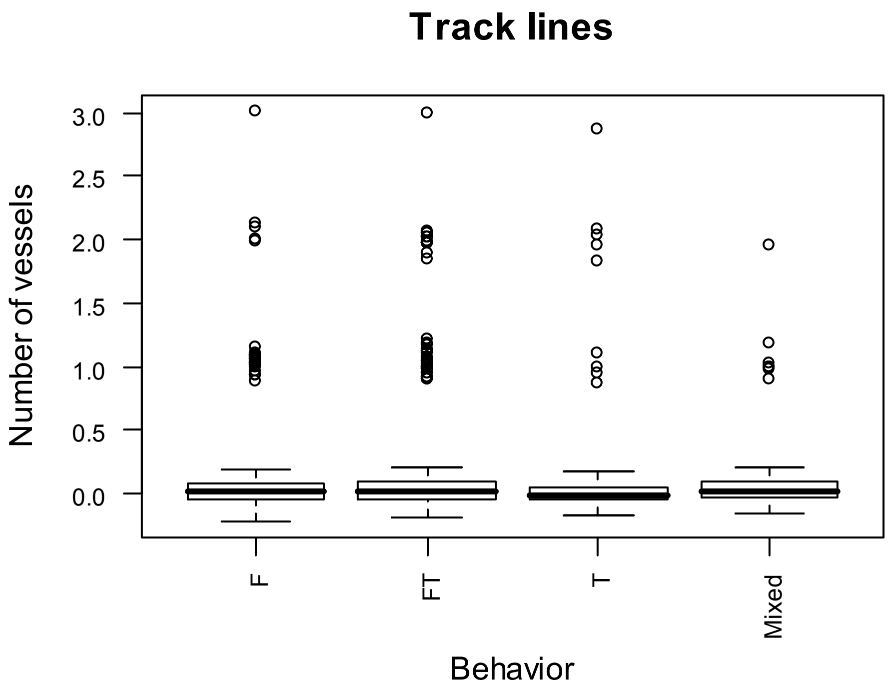


Figure B.7. Box and whisker plots of number of vessels by station. ***Number of vessels was jittered to show overlapping points*** **(i.e., a small amount of random noise was added to number of vessels for plotting purposes only to show overlapping points). Boxes as described in caption to Figure B.1.**



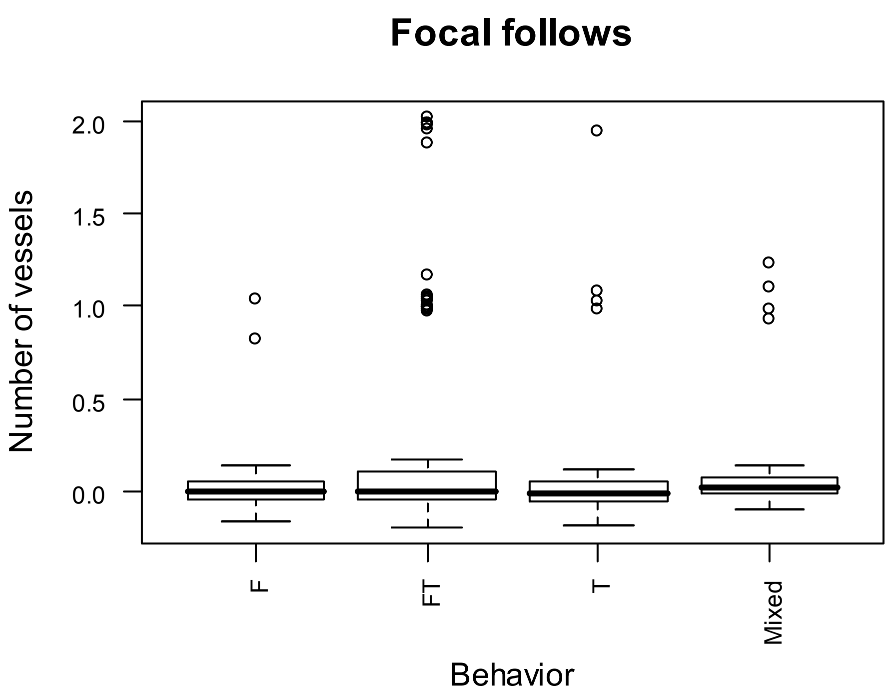
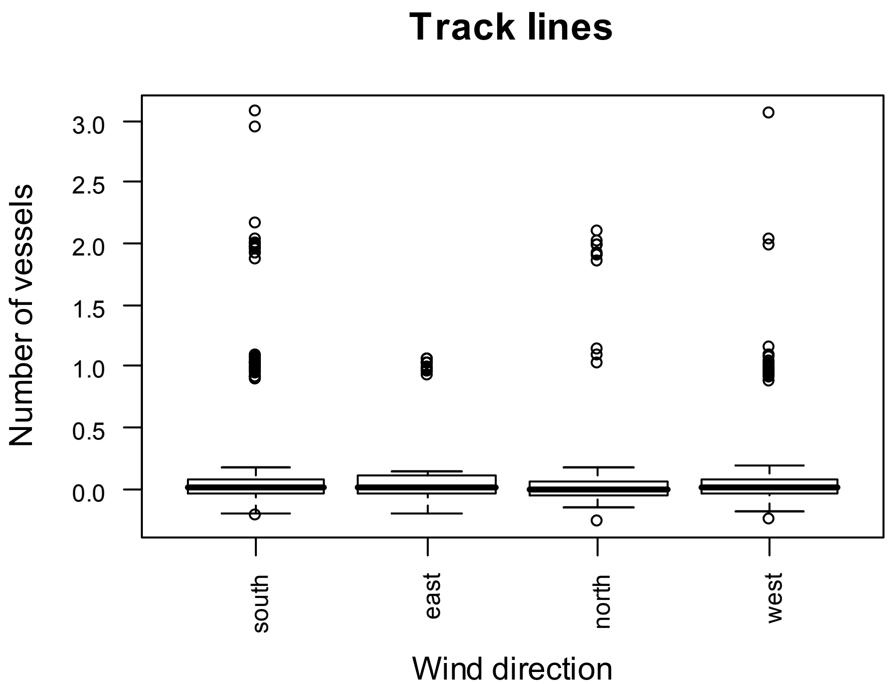


Figure B.8. Box and whisker plots of number of vessels by behavior. ***Number of vessels was jittered to show overlapping points*** **(i.e., a small amount of random noise was added to number of vessels for plotting purposes only to show overlapping points). Boxes as described in caption to Figure B.1.**



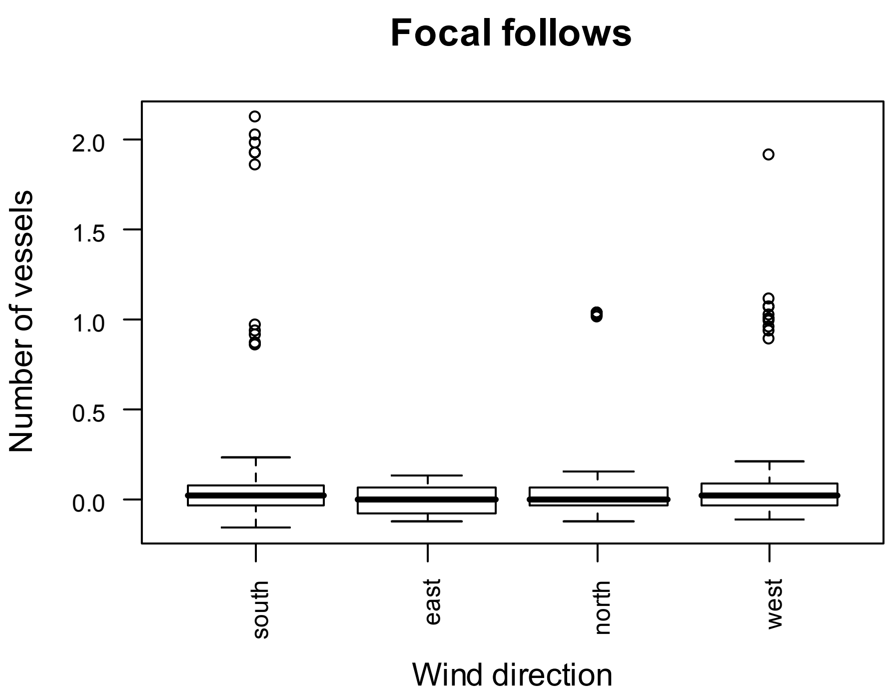
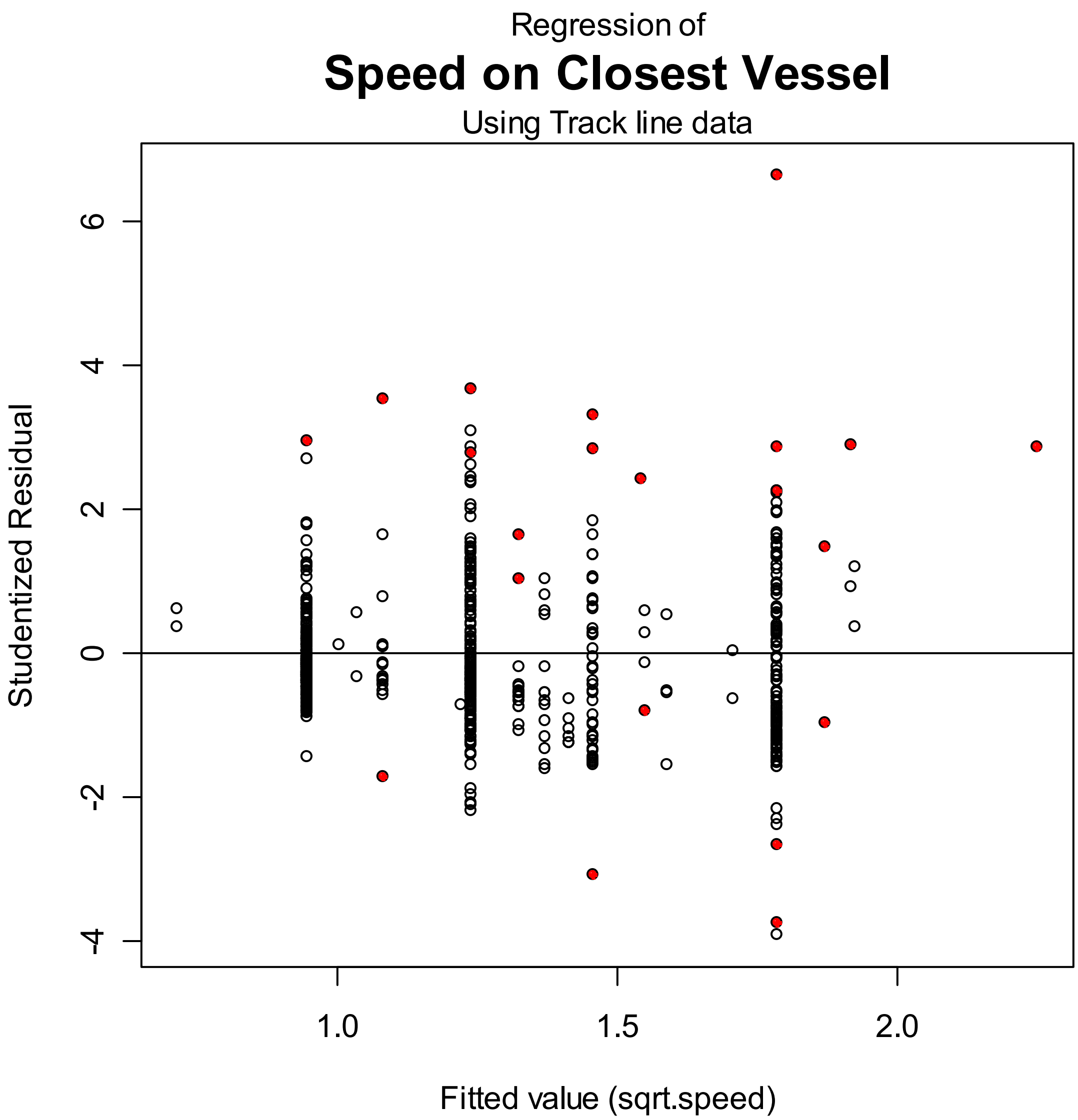
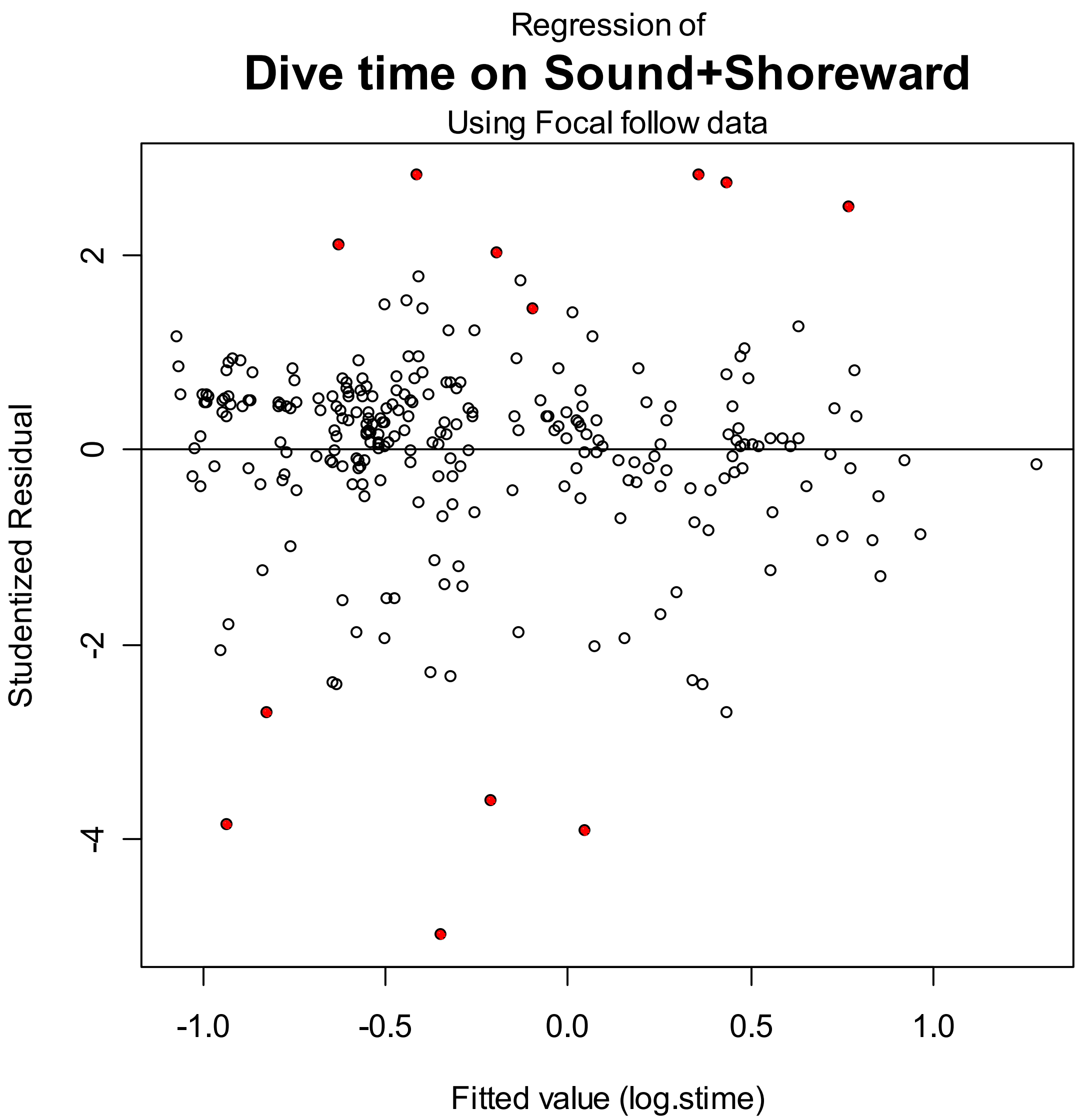
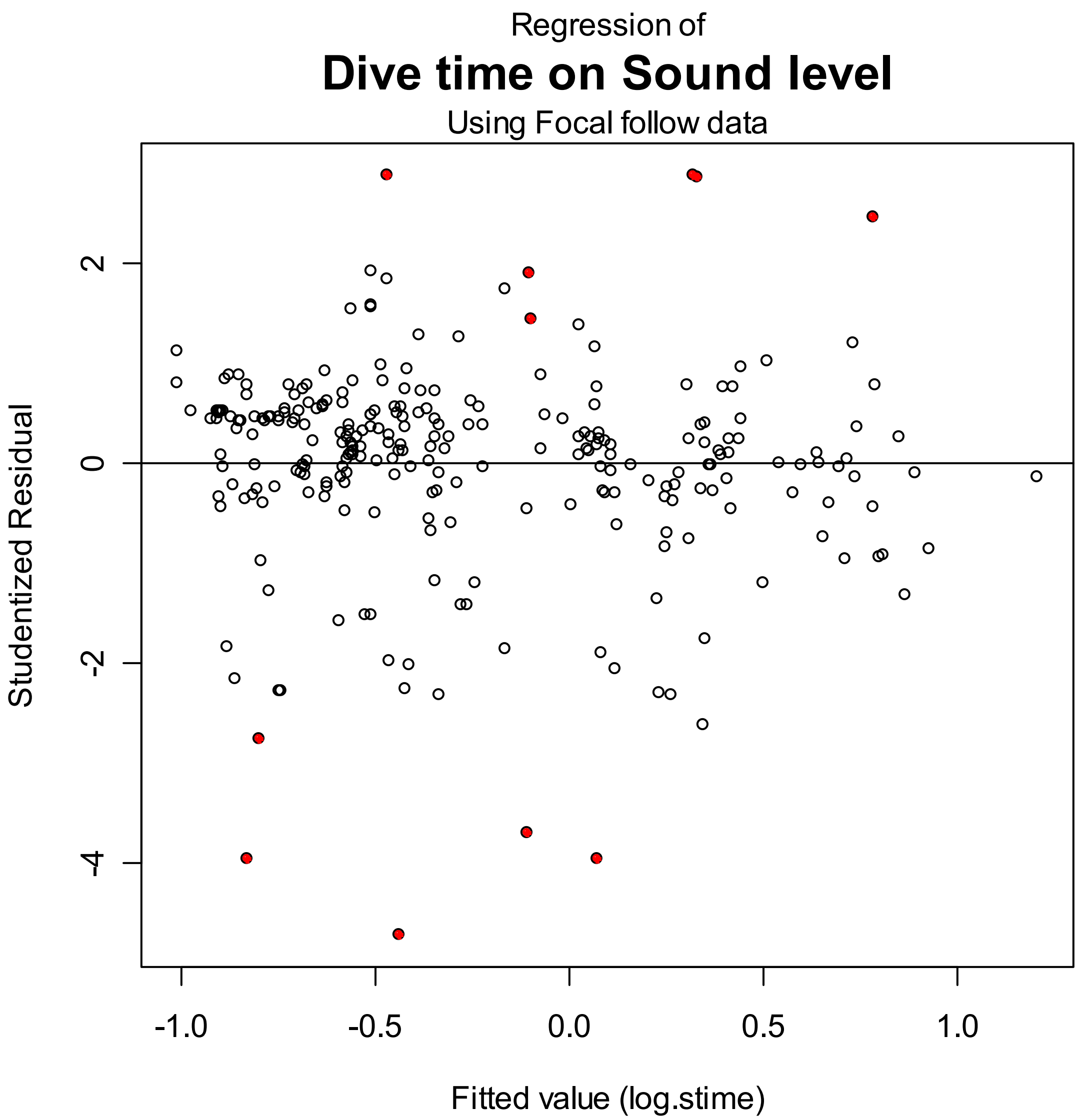


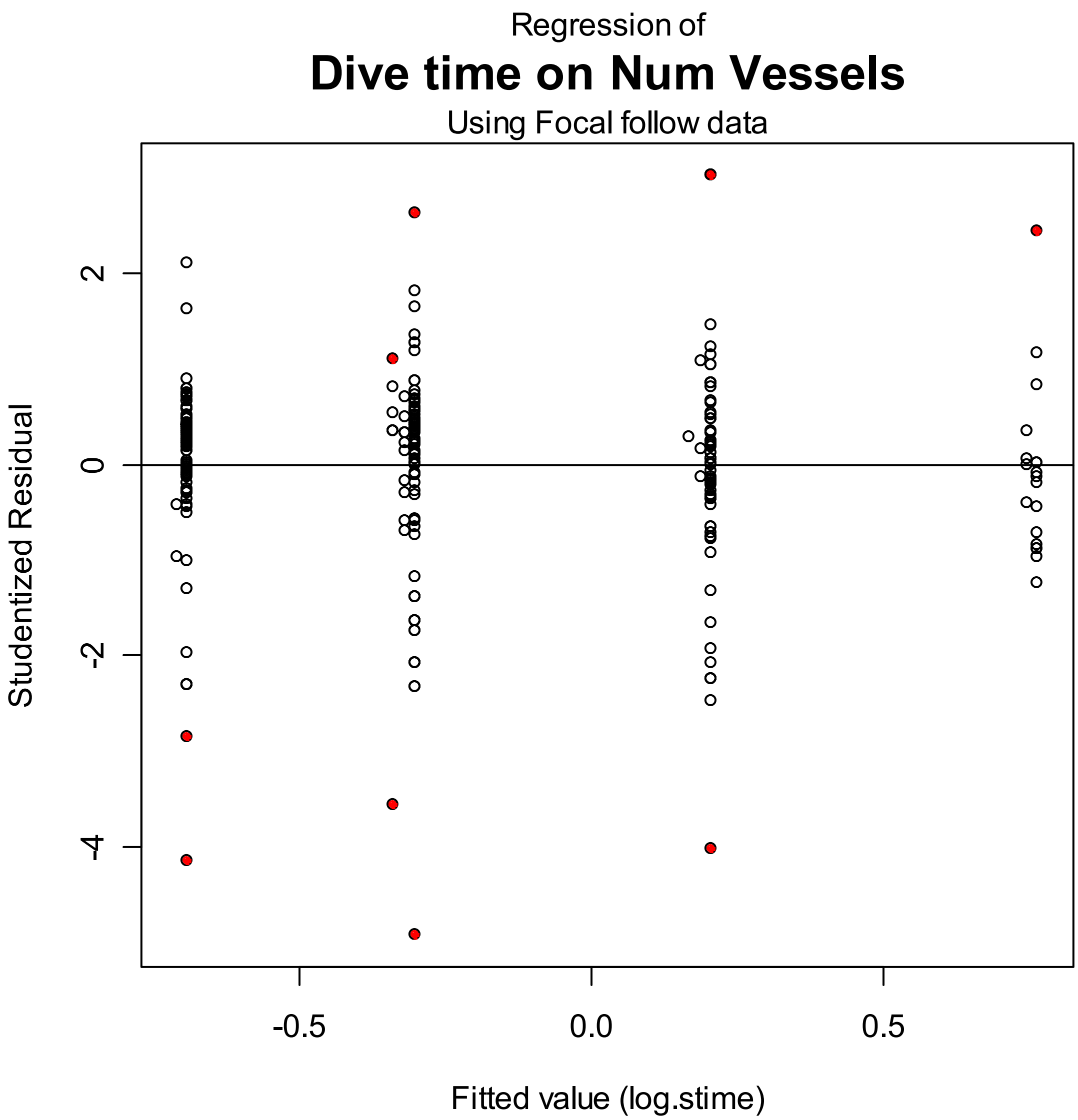
Figure B.9. Box and whisker plots of number of vessels by wind direction. ***Number of vessels was jittered to show overlapping points*** **(i.e., a small amount of random noise was added to number of**

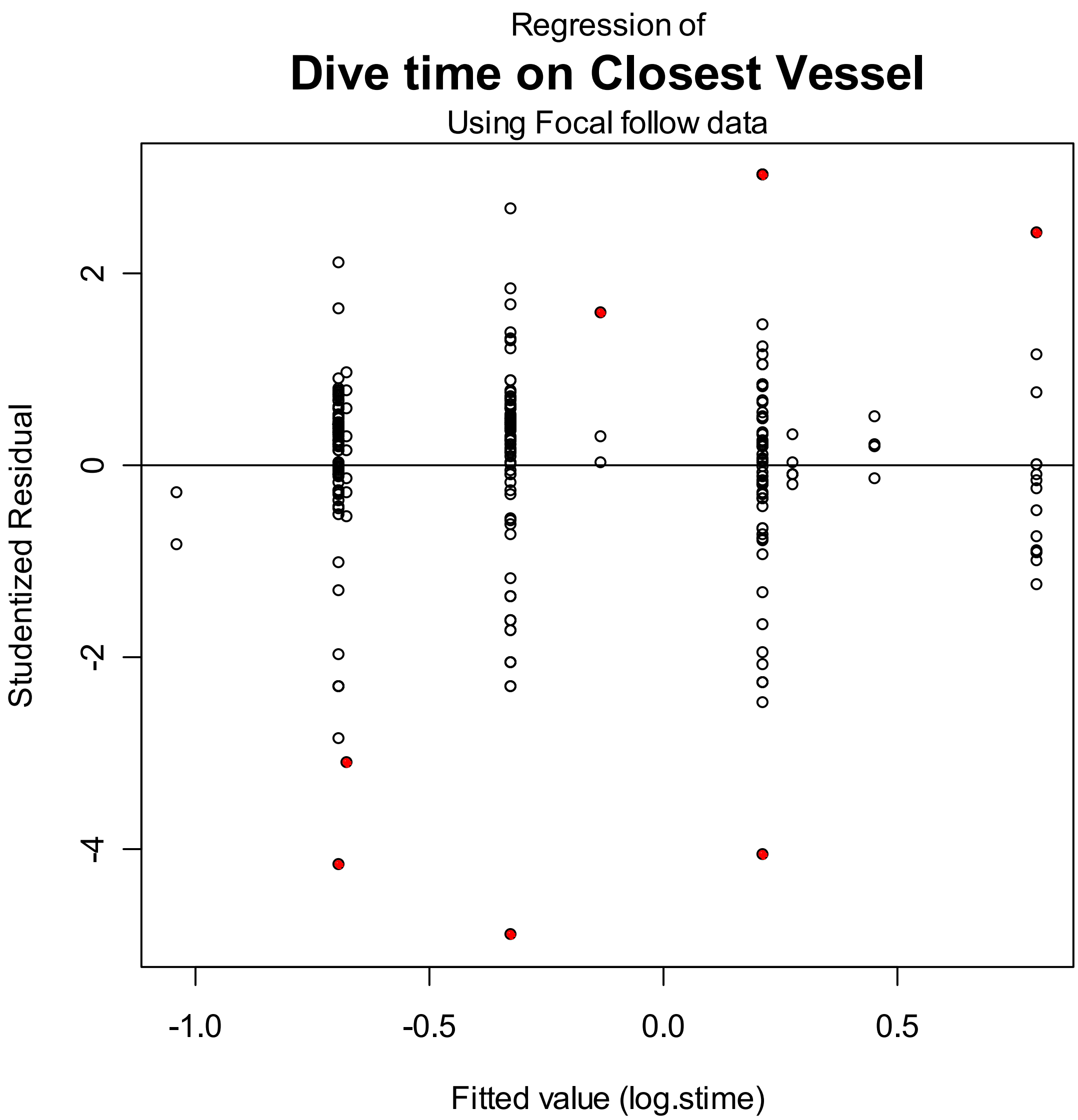
vessels for plotting purposes only to show overlapping points). Boxes as described in caption to Figure B.1.

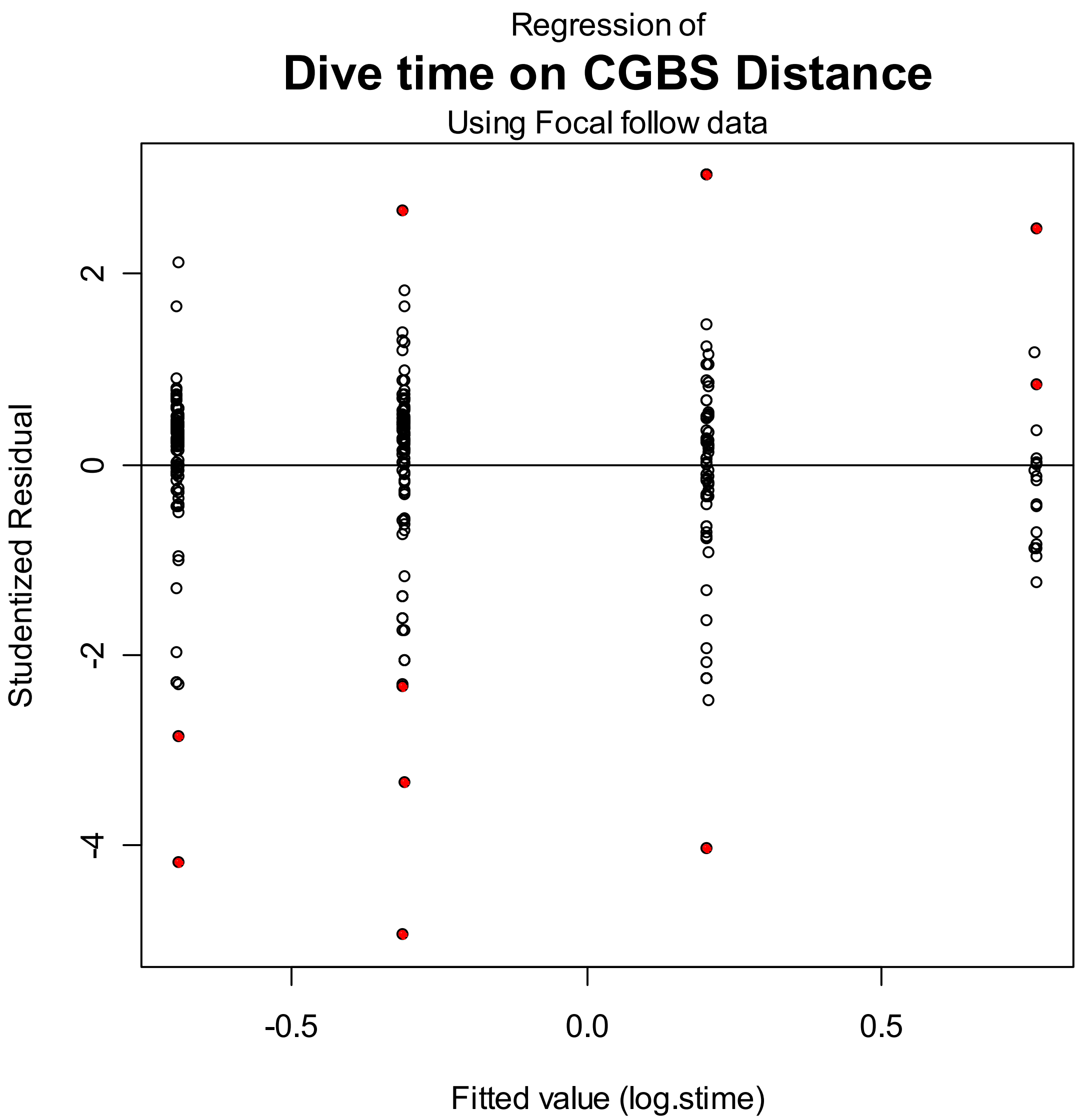

Regression of
Speed on Closest Vessel
Using Track line data
Studentized Residual
6
4
2
0
-2
-4
1.0
1.5
2.0
Fitted value (sqrt.speed)

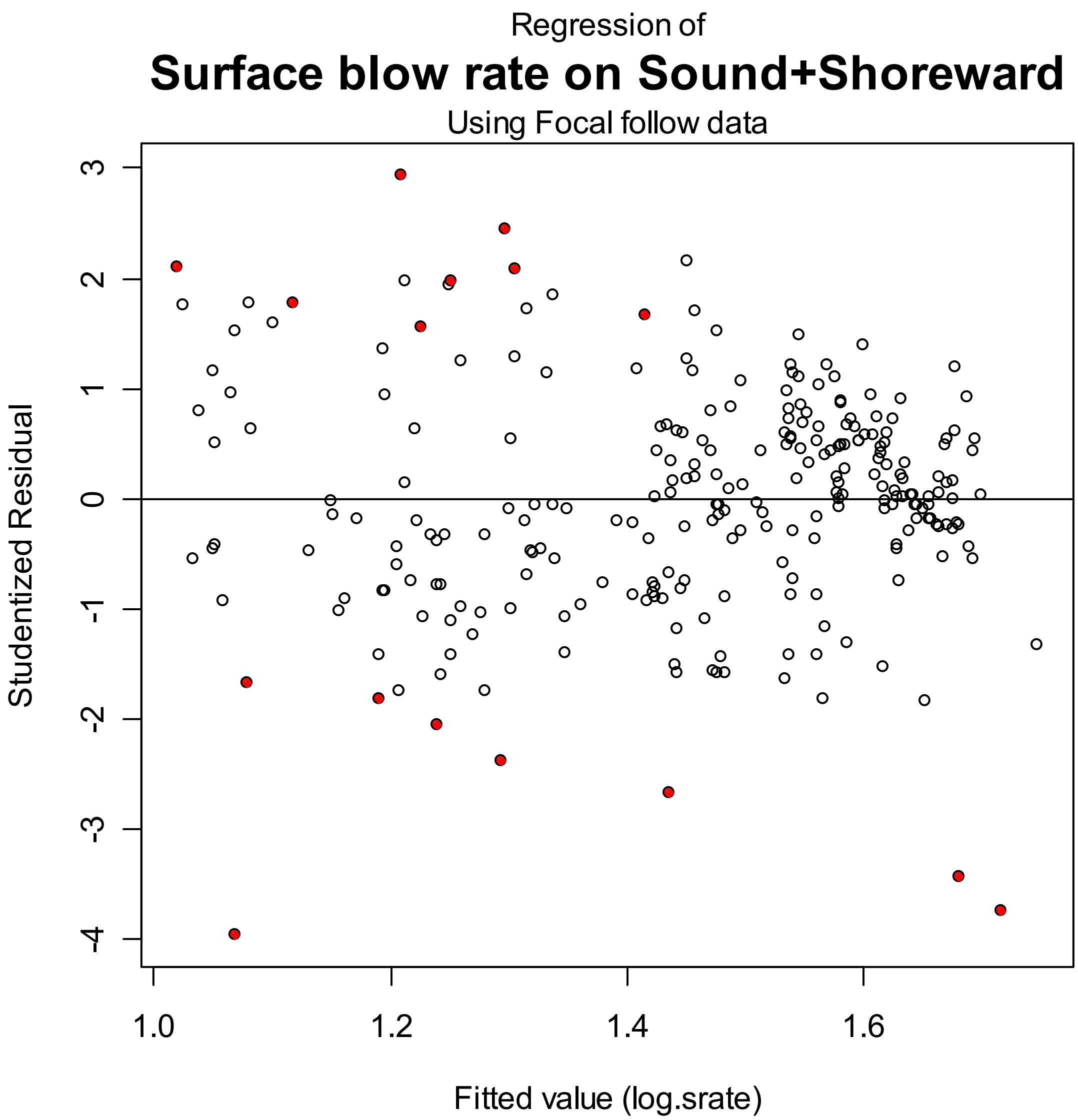

Regression of
Dive time on Sound+Shoreward
Using Focal follow data
Studentized Residual
Fitted value (log.stime)
2
0
-2
-4
-1.0
-0.5
0.0
0.5
1.0

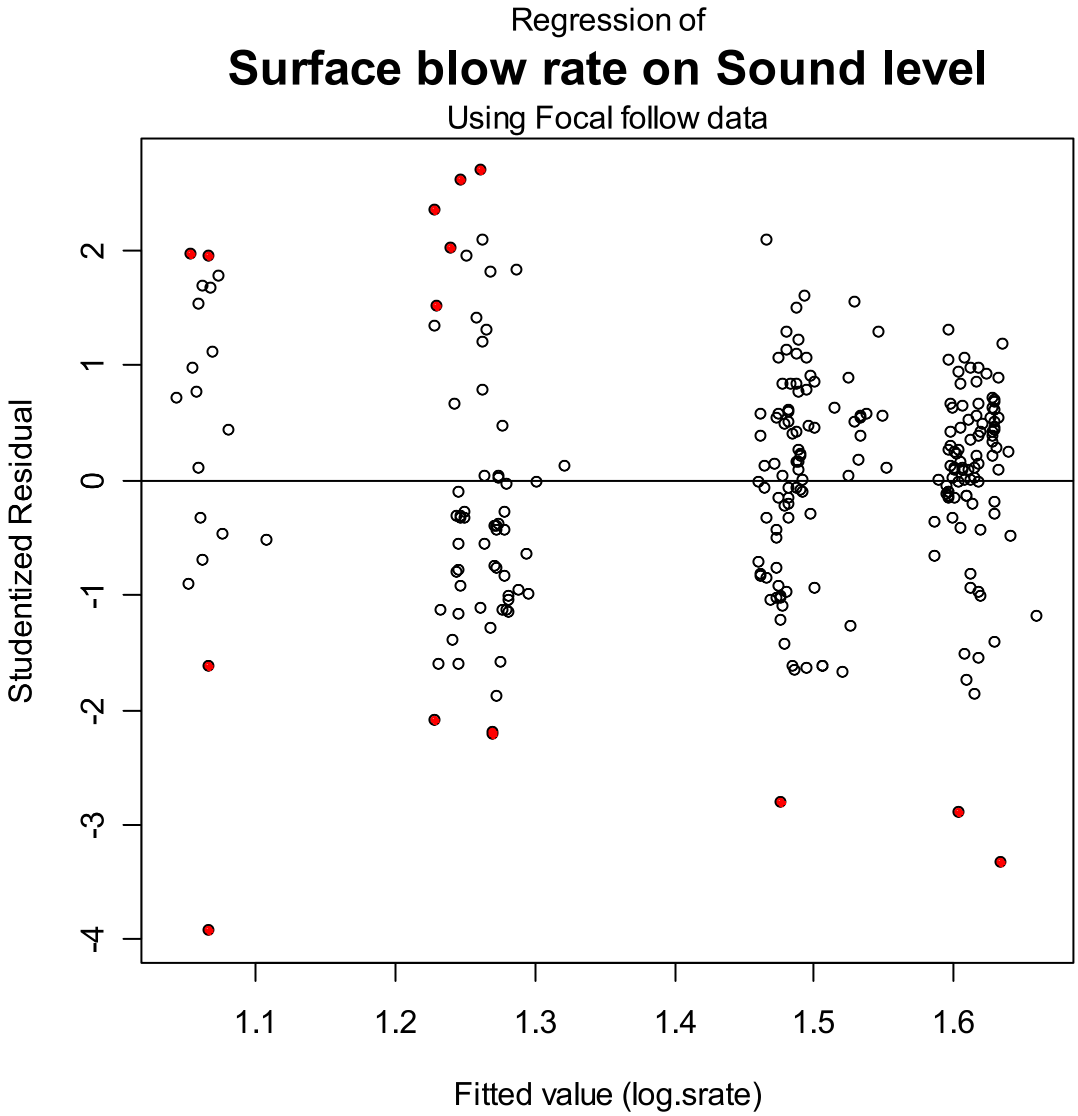

Regression of
Dive time on Sound level
Using Focal follow data
Studentized Residual
Fitted value (log.stime)
2
0
-2
-4
-1.0
-0.5
0.0
0.5
1.0

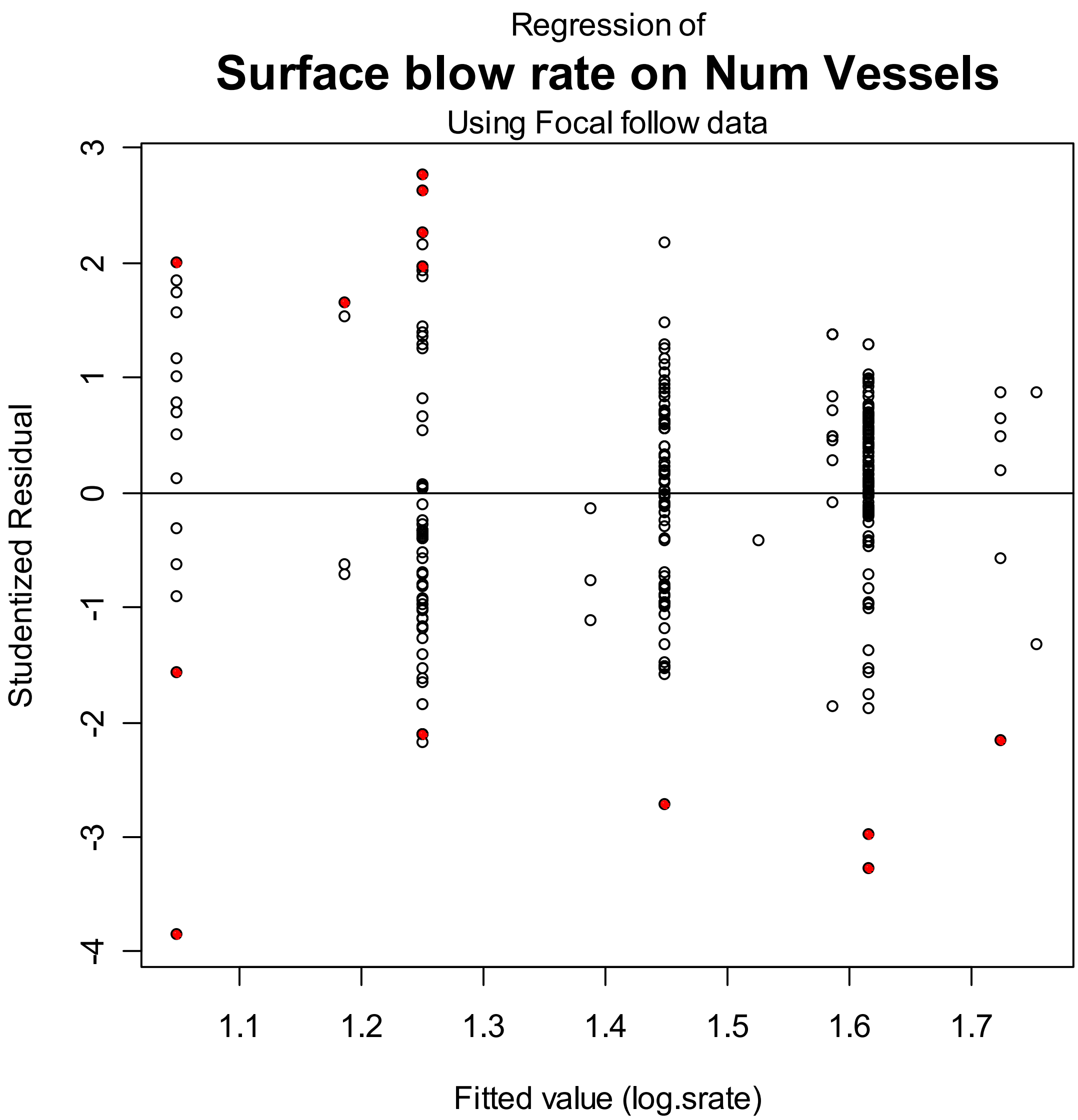

Regression of
Dive time on Num Vessels
Using Focal follow data
Studentized Residual
2
0
-2
-4
-0.5
0.0
0.5
Fitted value (log.stime)

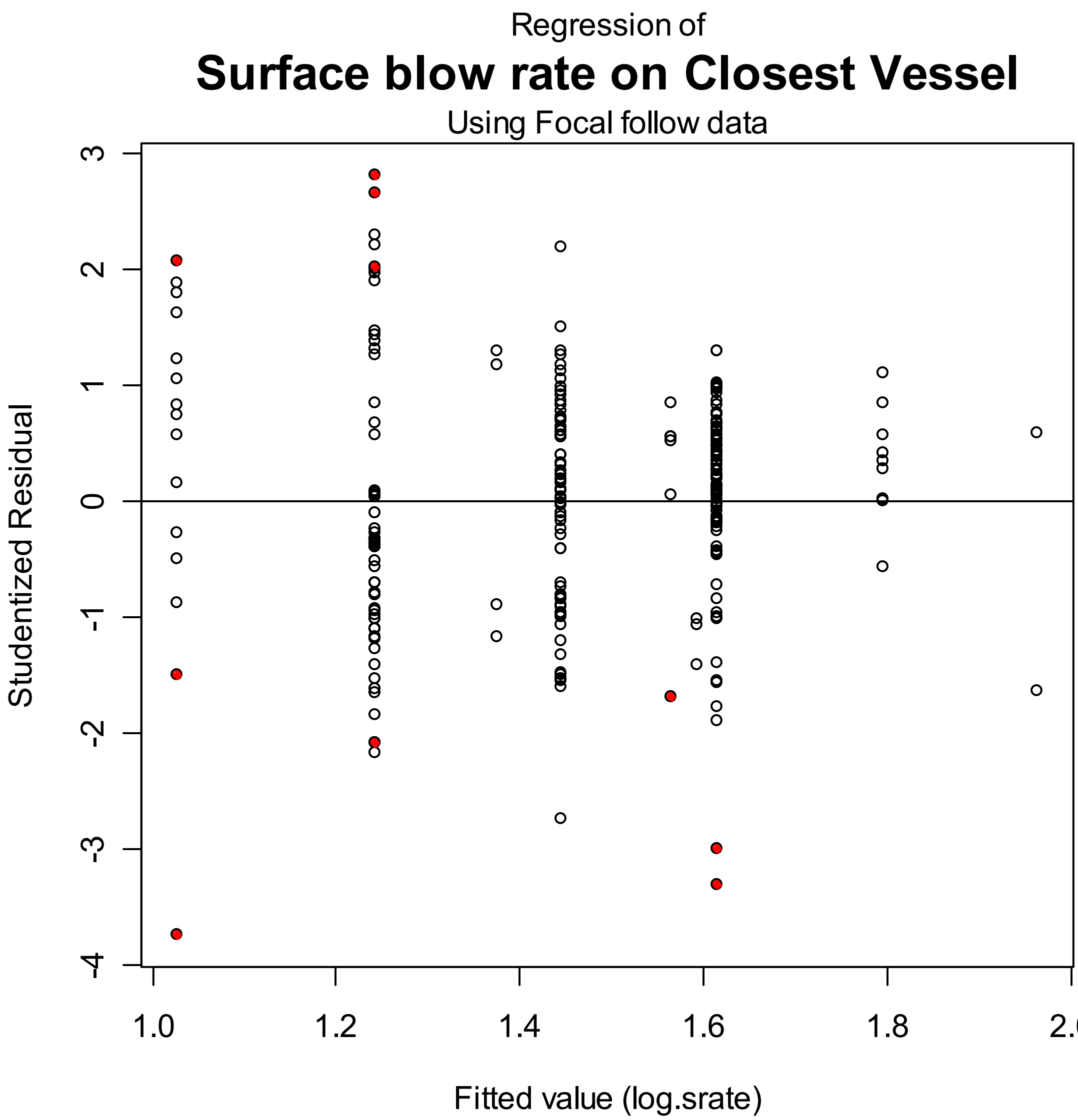

Regression of
Dive time on Closest Vessel
Using Focal follow data
Studentized Residual
2
0
-2
-4
-1.0
-0.5
0.0
0.5
Fitted value (log.stime)

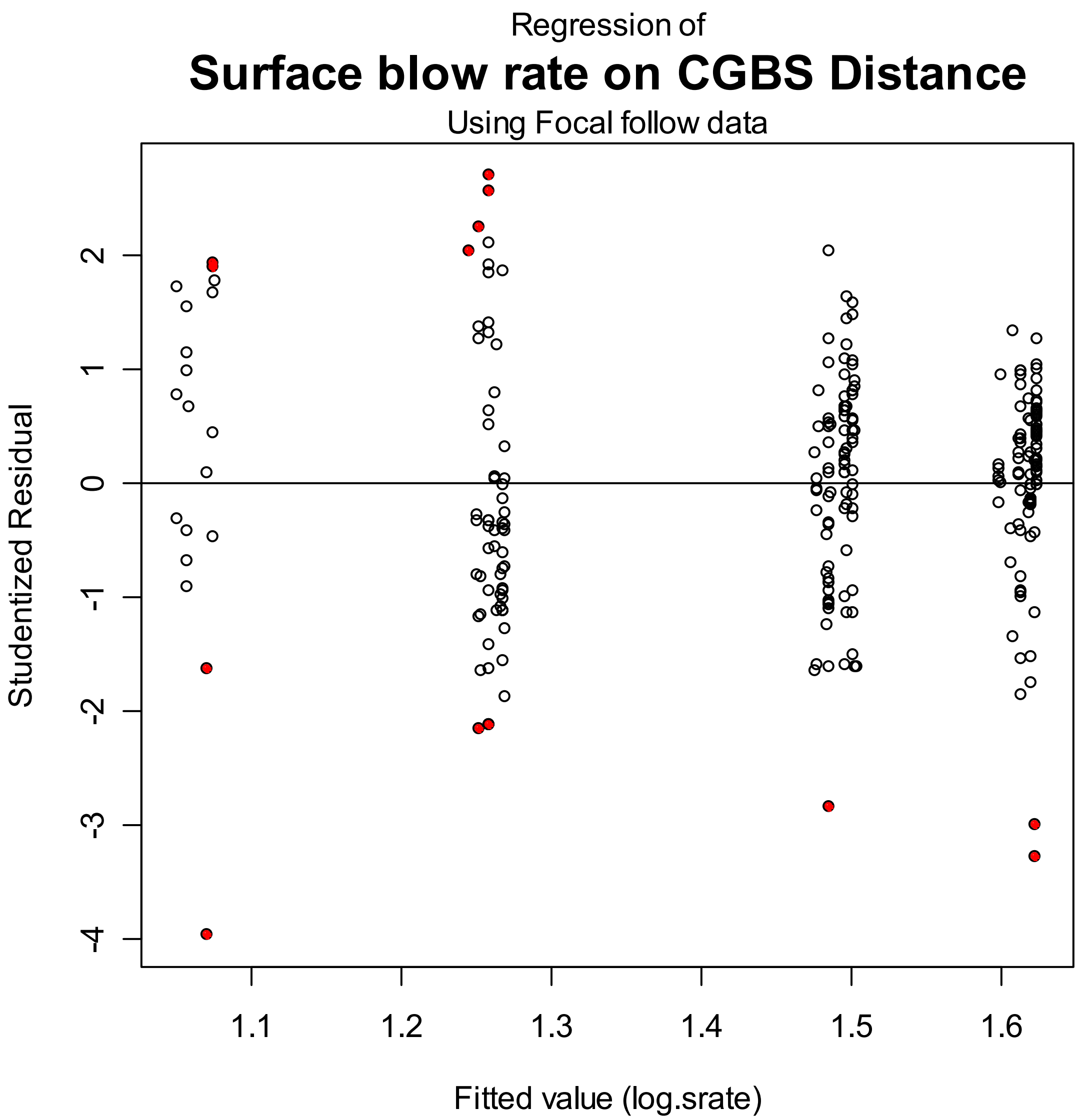

Regression of
Dive time on CGBS Distance
Using Focal follow data
Studentized Residual
2
0
-2
-4
-0.5
0.0
0.5
Fitted value (log.stime)


Regression of
Surface blow rate on Sound+Shoreward
Using Focal follow data
Studentized Residual
3
2
1
0
-1
-2
-3
-4
1.0
1.2
1.4
1.6
Fitted value (log.srate)


Regression of
Surface blow rate on Sound level
Using Focal follow data
Studentized Residual
Fitted value (log.srate)
-4
-3
-2
-1
0
1
2
1.1
1.2
1.3
1.4
1.5
1.6


Regression of
Surface blow rate on Num Vessels
Using Focal follow data
Studentized Residual
Fitted value (log.srate)
3
2
1
0
-1
-2
-3
-4
1.1
1.2
1.3
1.4
1.5
1.6
1.7

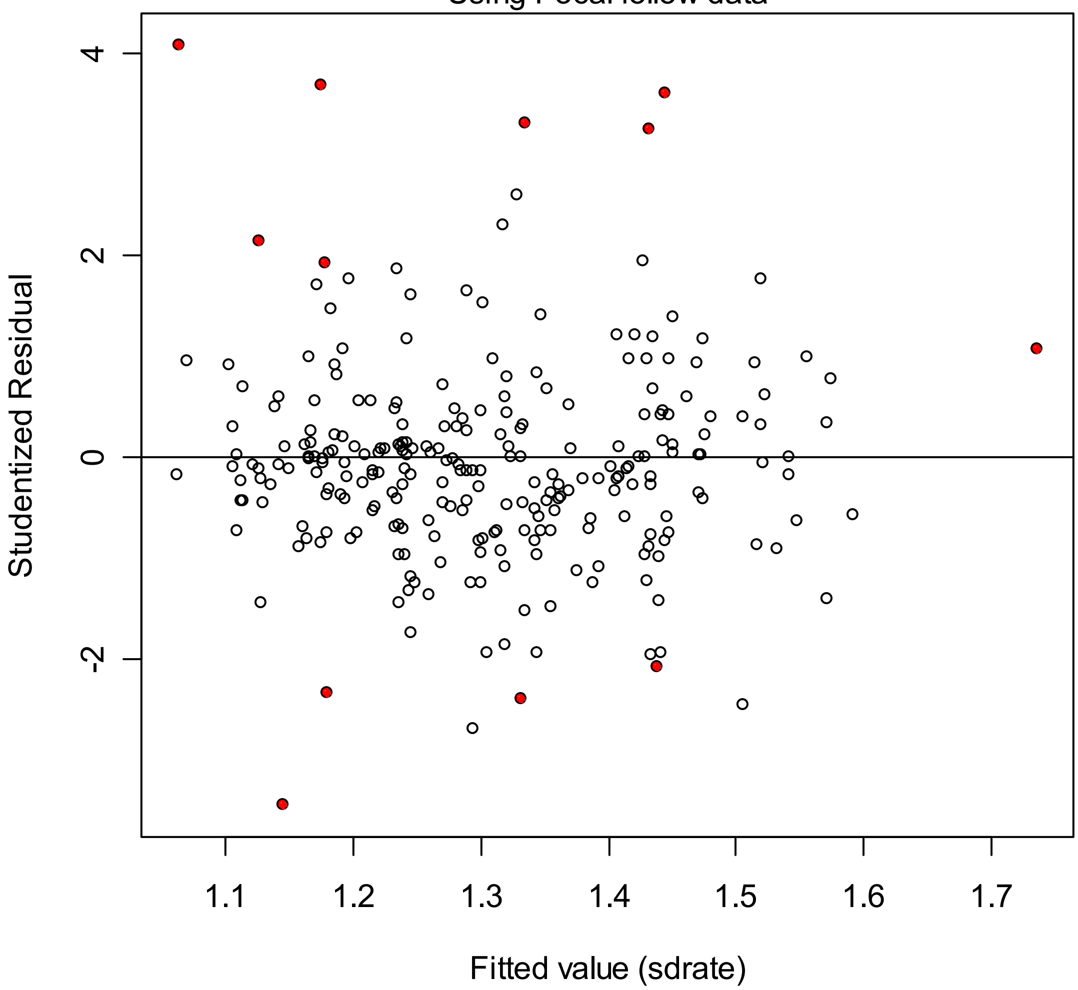

Regression of
Surface blow rate on Closest Vessel
Using Focal follow data
Studentized Residual
Fitted value (log.srate)
3
2
1
0
-1
-2
-3
-4
1.0
1.2
1.4
1.6
1.8
2.0

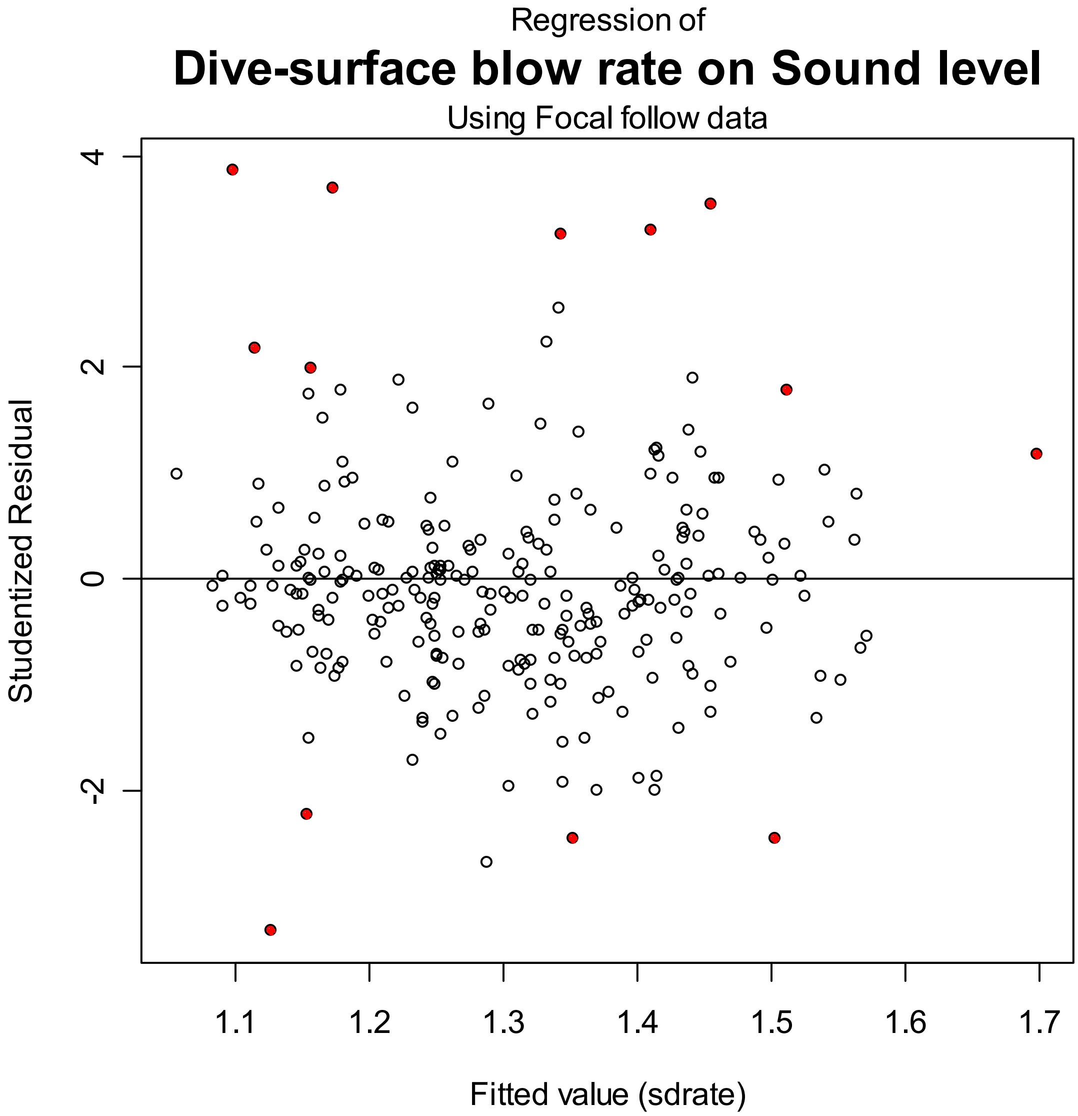

Regression of
Surface blow rate on CGBS Distance
Using Focal follow data
Studentized Residual
2
1
0
-1
-2
-3
-4
1.1
1.2
1.3
1.4
1.5
1.6
Fitted value (log.srate)

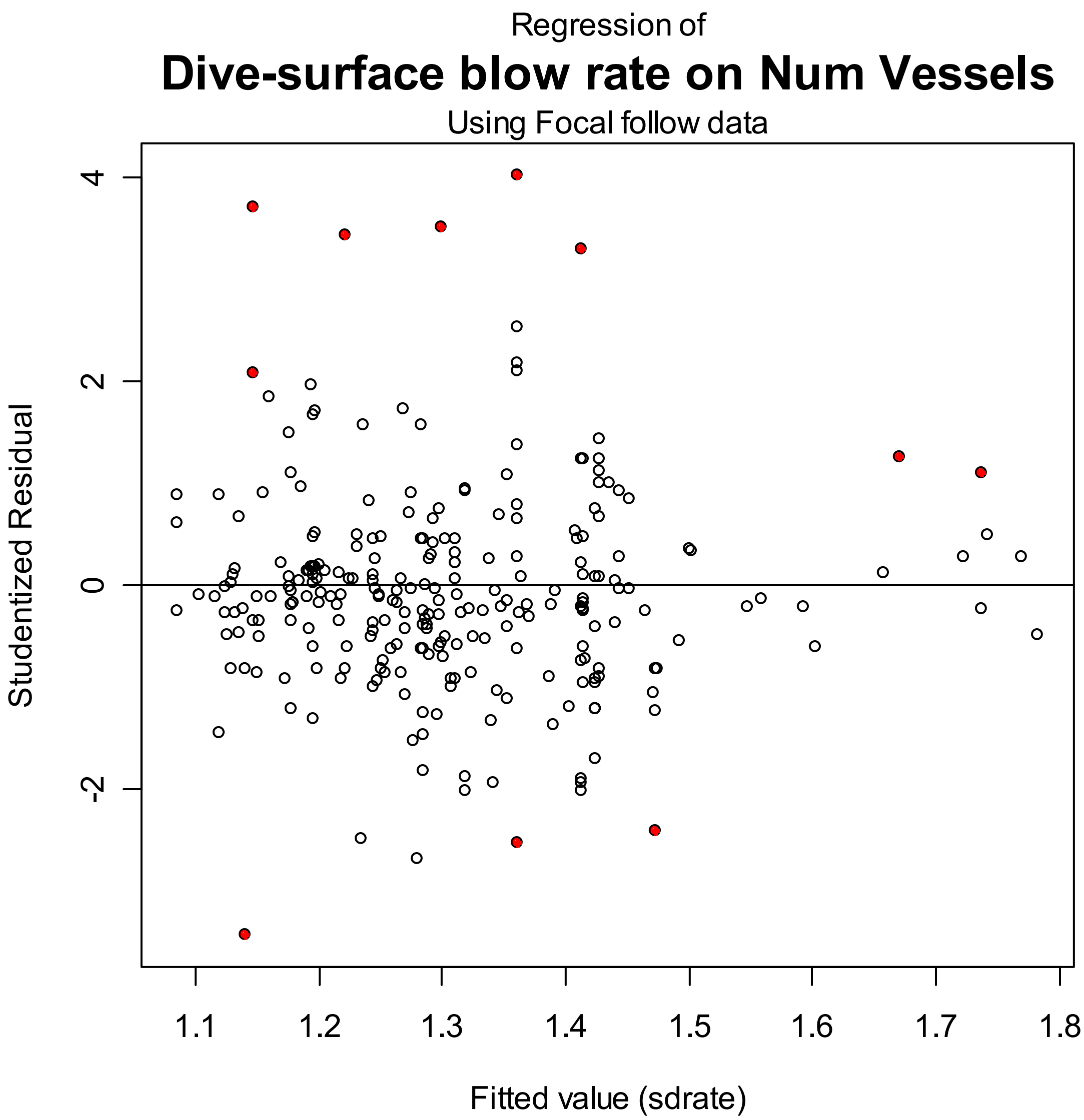
Regression of

Dive-surface blow rate on Sound+Shoreward

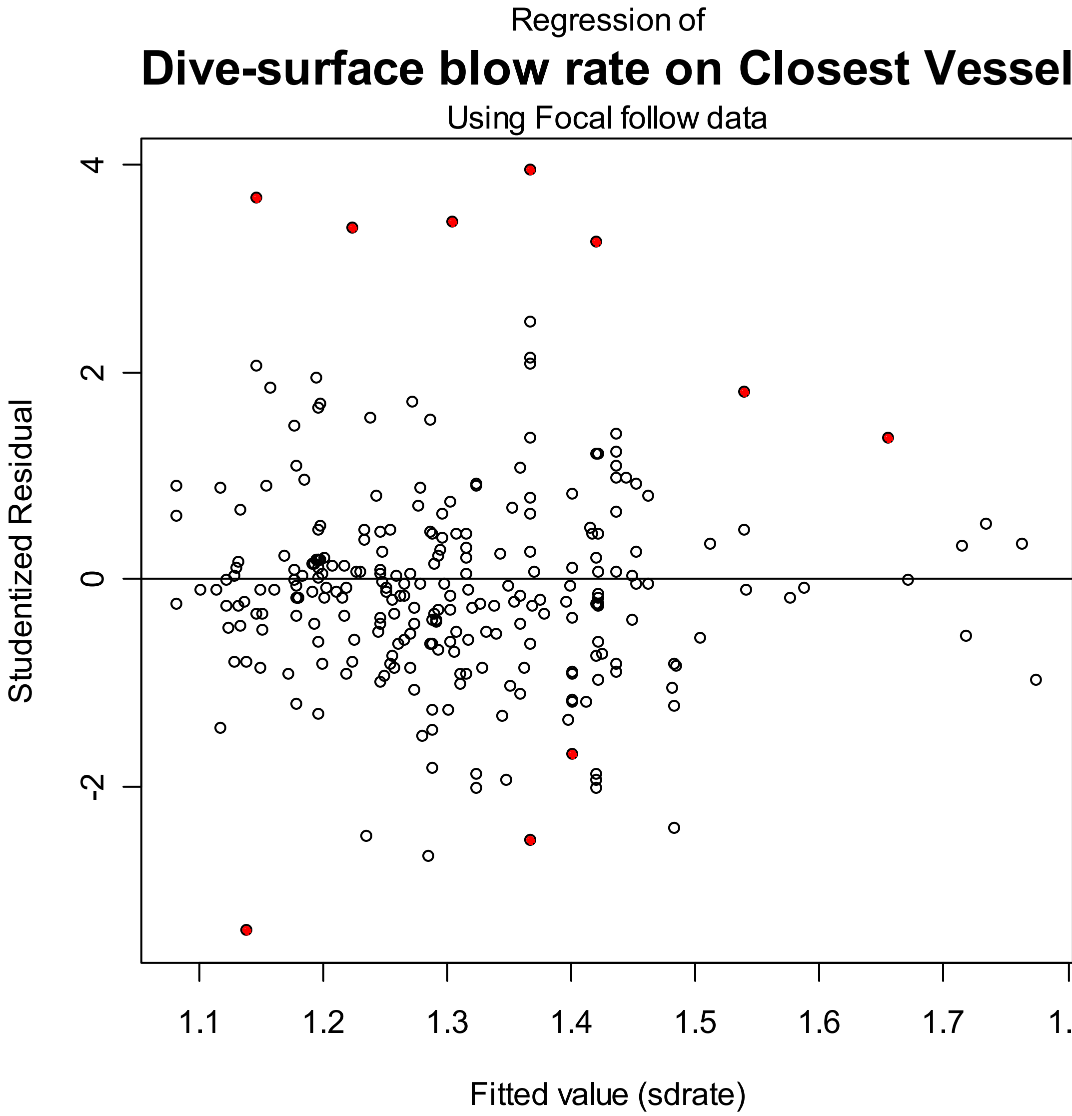
Using Focal follow data

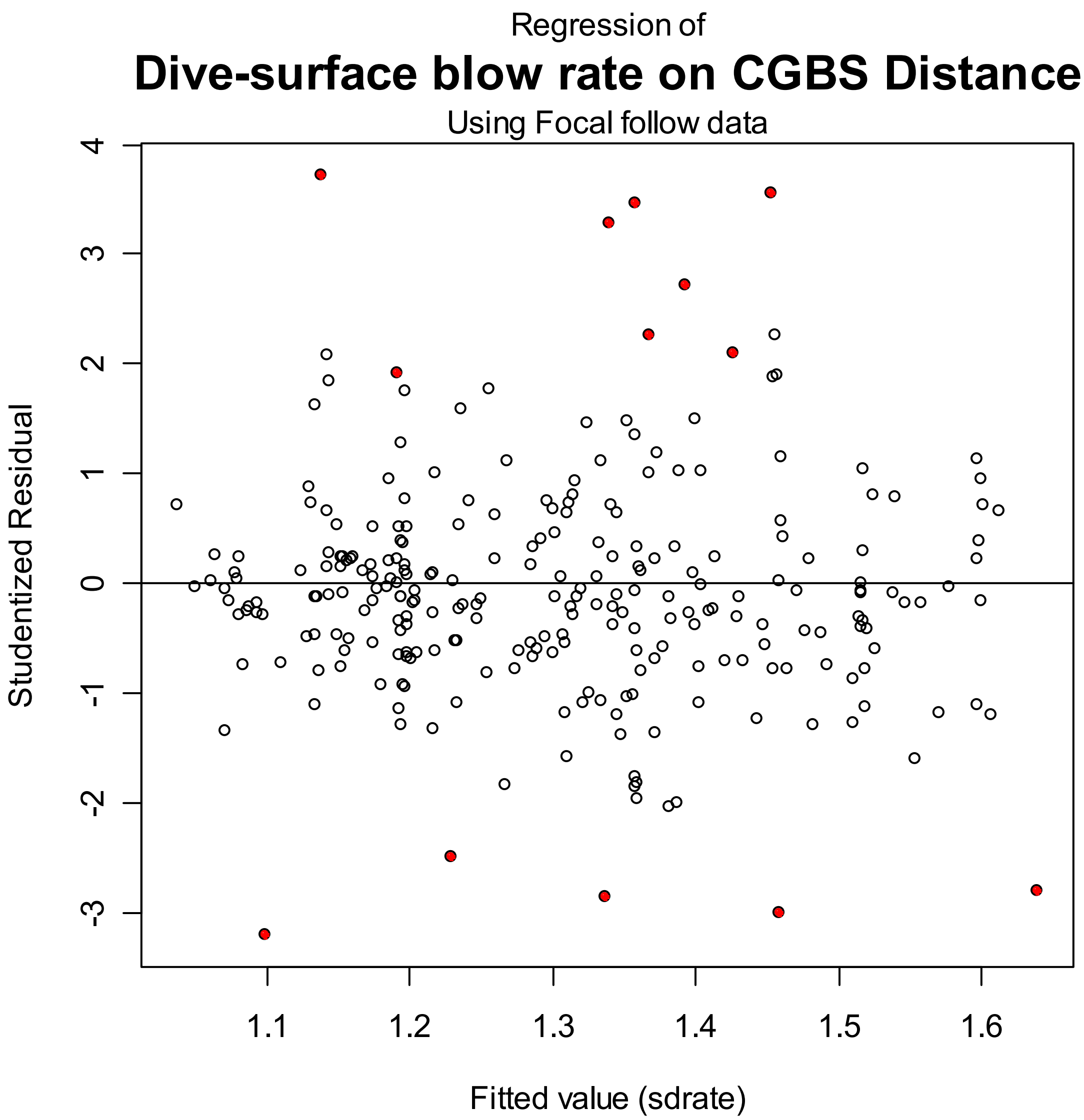


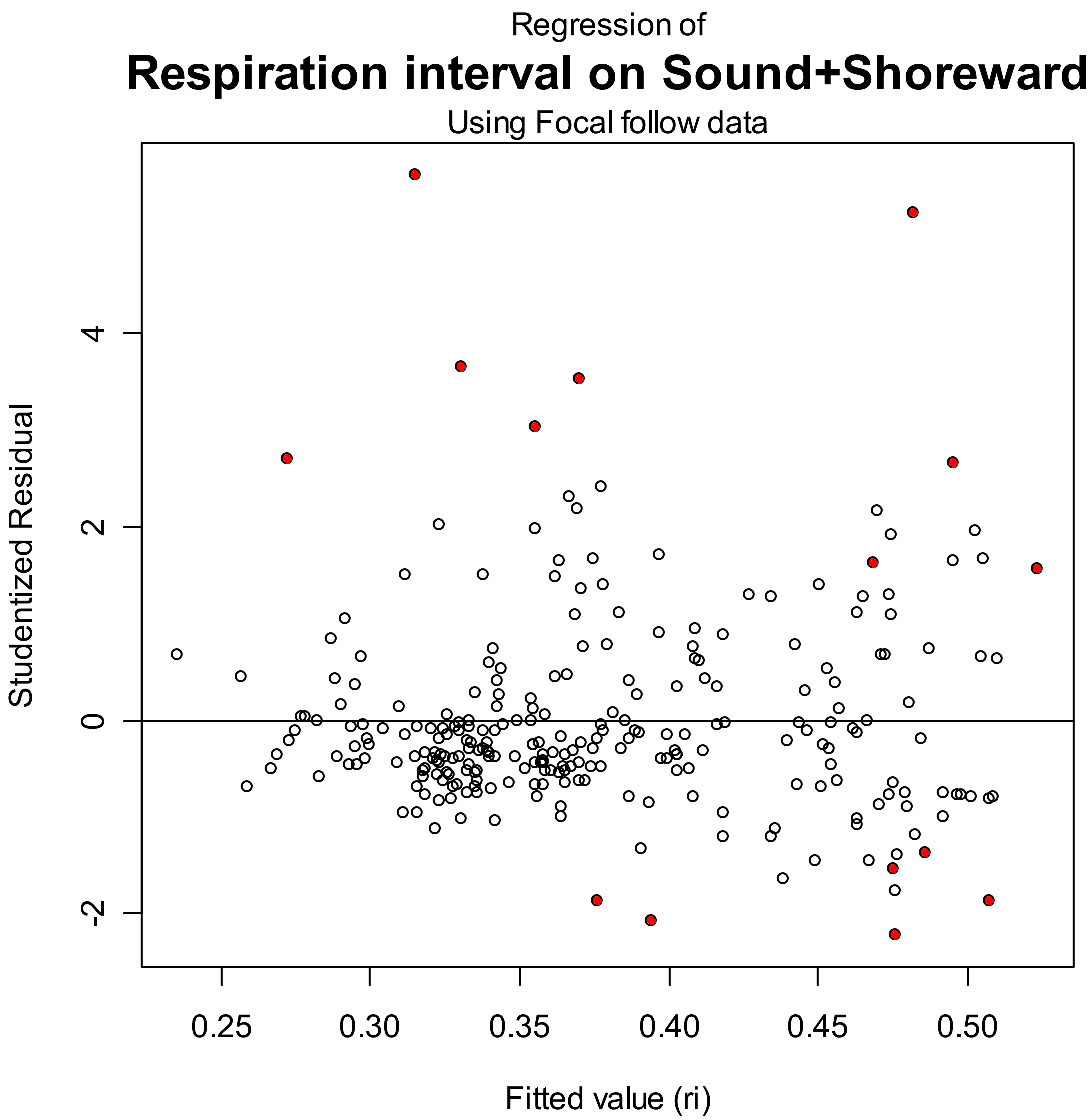

Regression of
Dive-surface blow rate on Sound level
Using Focal follow data
Studentized Residual
Fitted value (sdrate)
4
2
0
-2
1.1
1.2
1.3
1.4
1.5
1.6
1.7

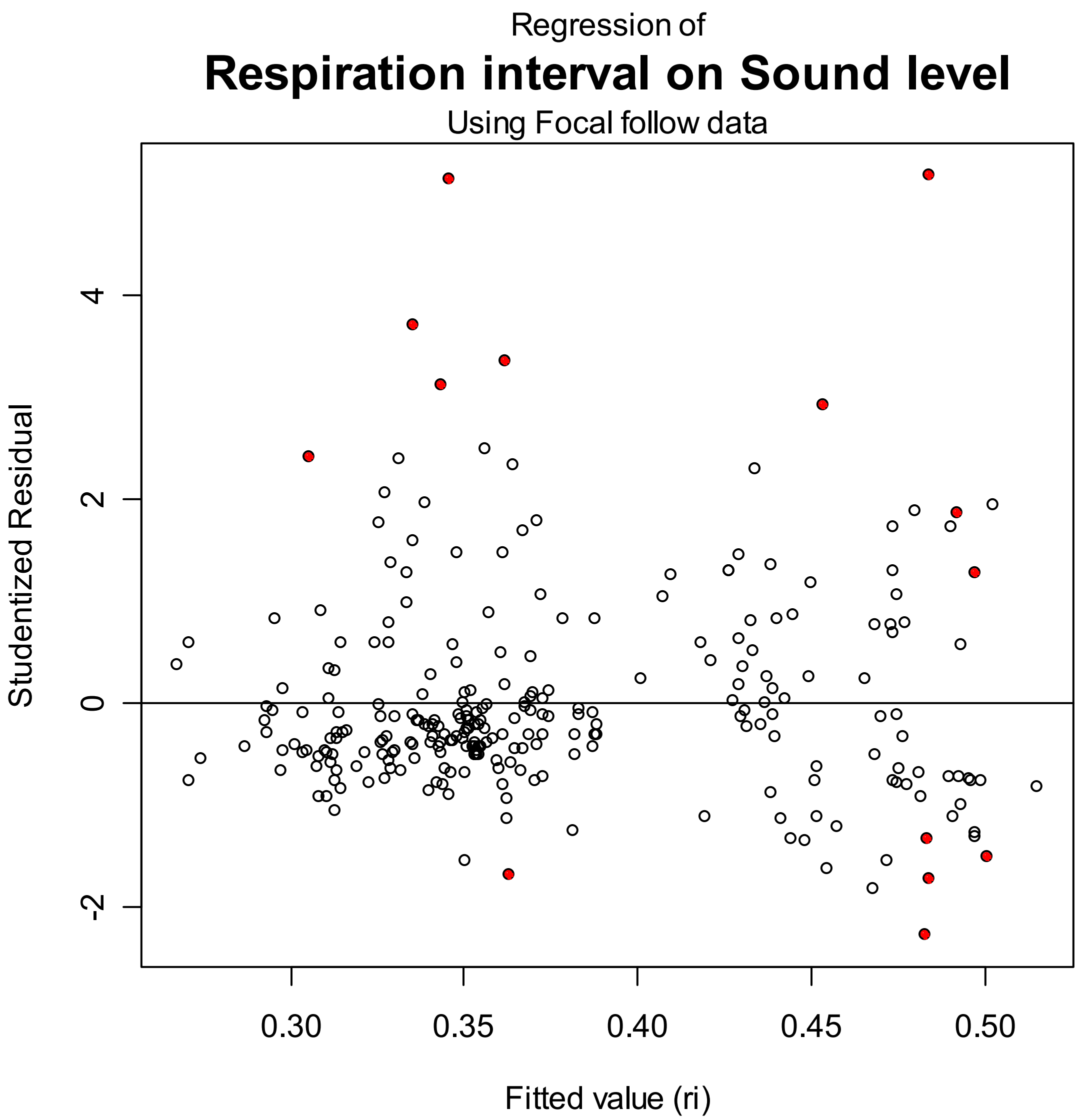


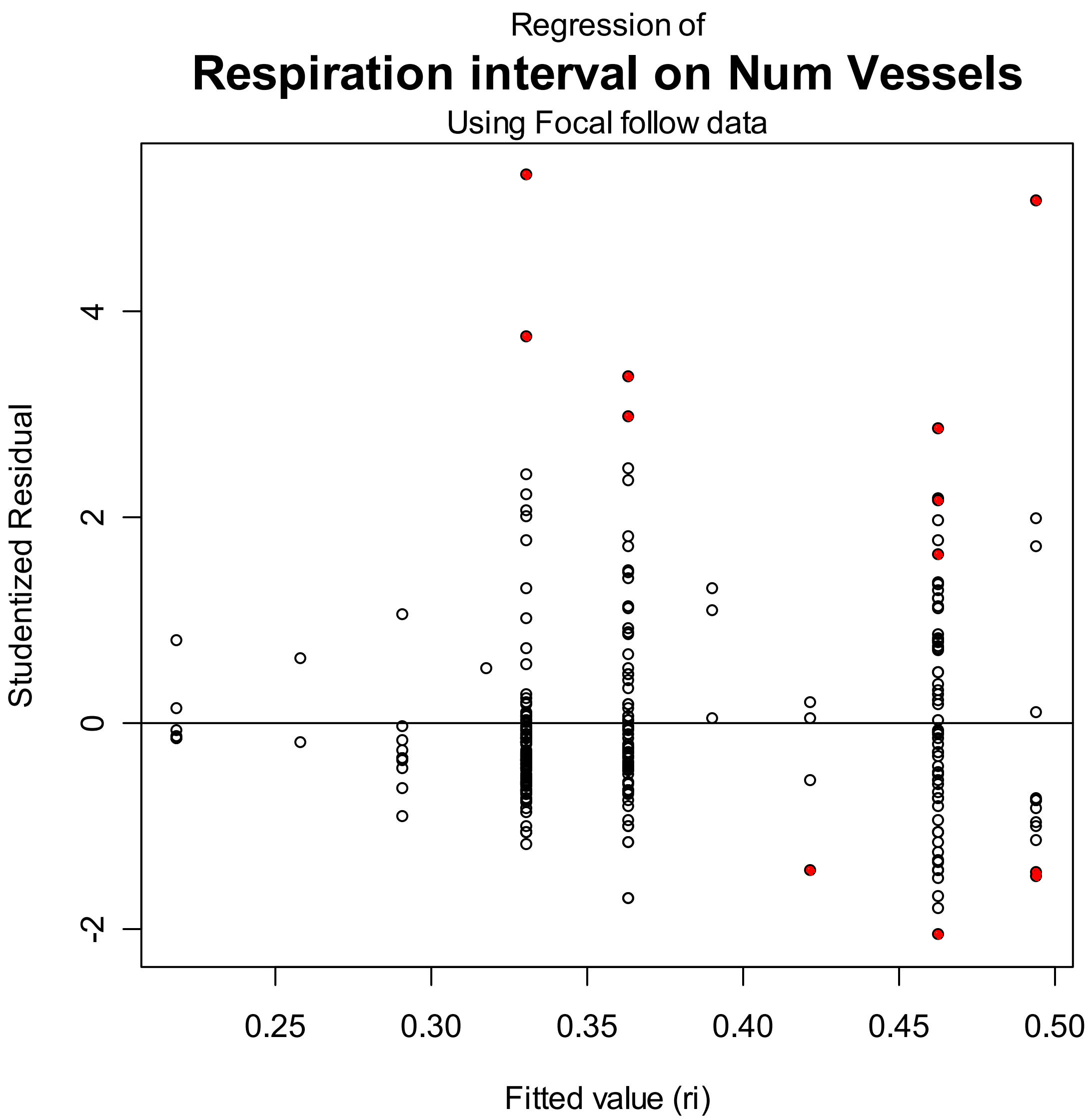
Regression of
Dive-surface blow rate on Num Vessels
Using Focal follow data
Studentized Residual
4
2
0
-2
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
Fitted value (sdrate)

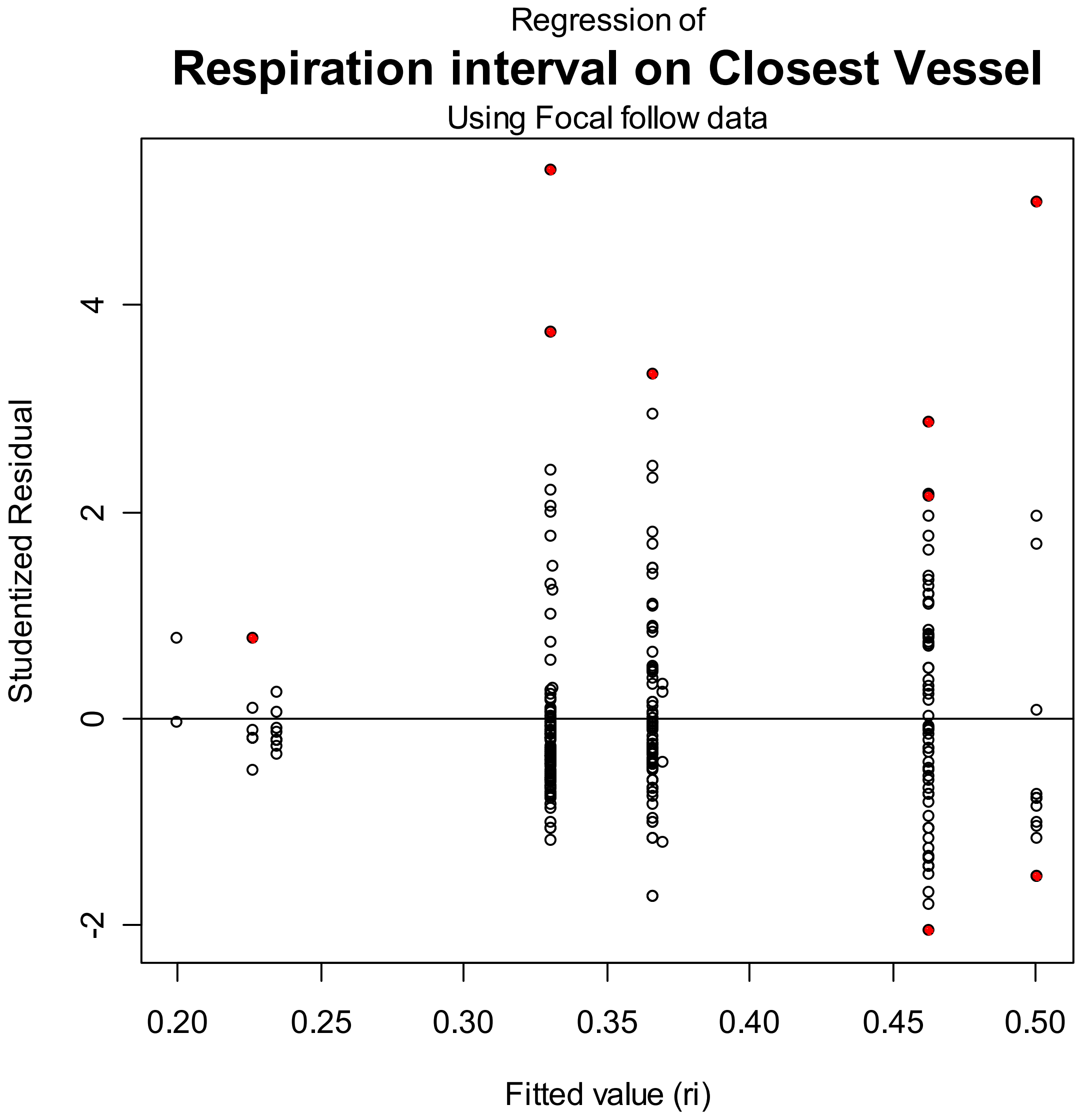

Regression of
Dive-surface blow rate on Closest Vessel
Using Focal follow data
Studentized Residual
4
2
0
-2
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
Fitted value (sdrate)

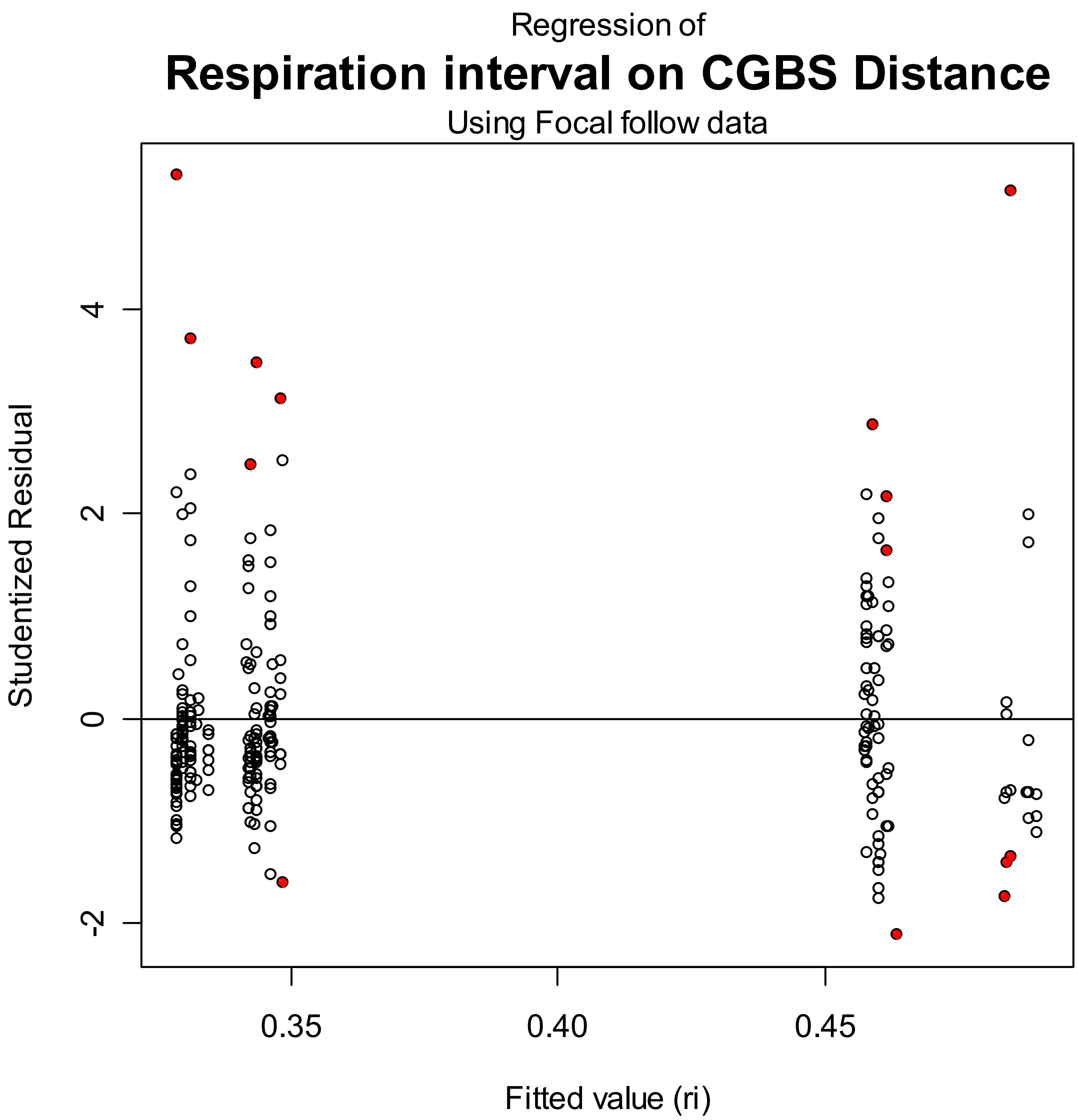

Regression of
Dive-surface blow rate on CGBS Distance
Using Focal follow data
Studentized Residual
4
3
2
1
0
-1
-2
-3
1.1
1.2
1.3
1.4
1.5
1.6
Fitted value (sdrate)

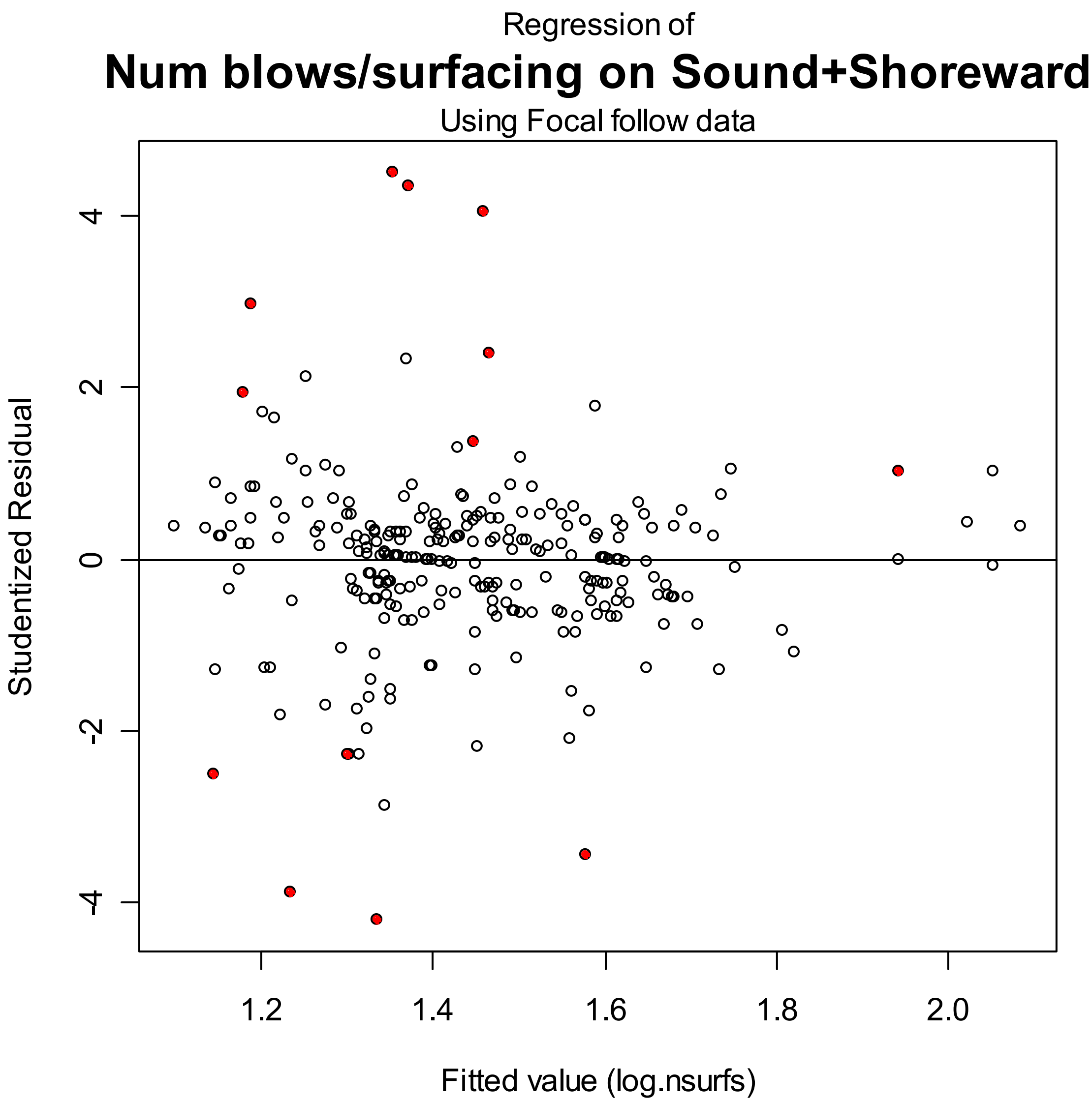

Regression of
Respiration interval on Sound+Shoreward
Using Focal follow data
Studentized Residual
Fitted value (ri)
-2
0
2
4
0.25
0.30
0.35
0.40
0.45
0.50

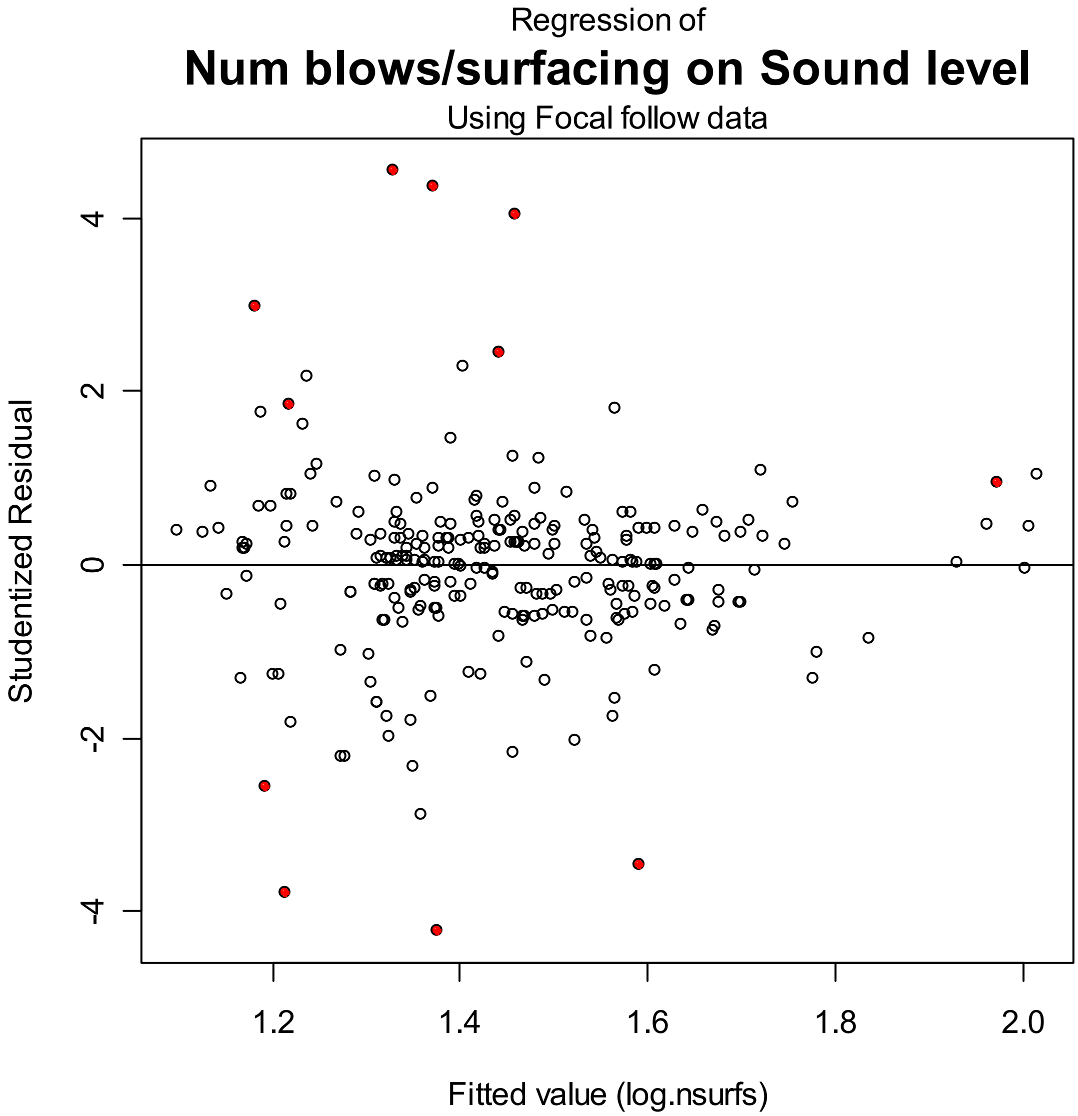

Regression of
Respiration interval on Sound level
Using Focal follow data
Studentized Residual
-2
0
2
4
0.30
0.35
0.40
0.45
0.50
Fitted value (ri)

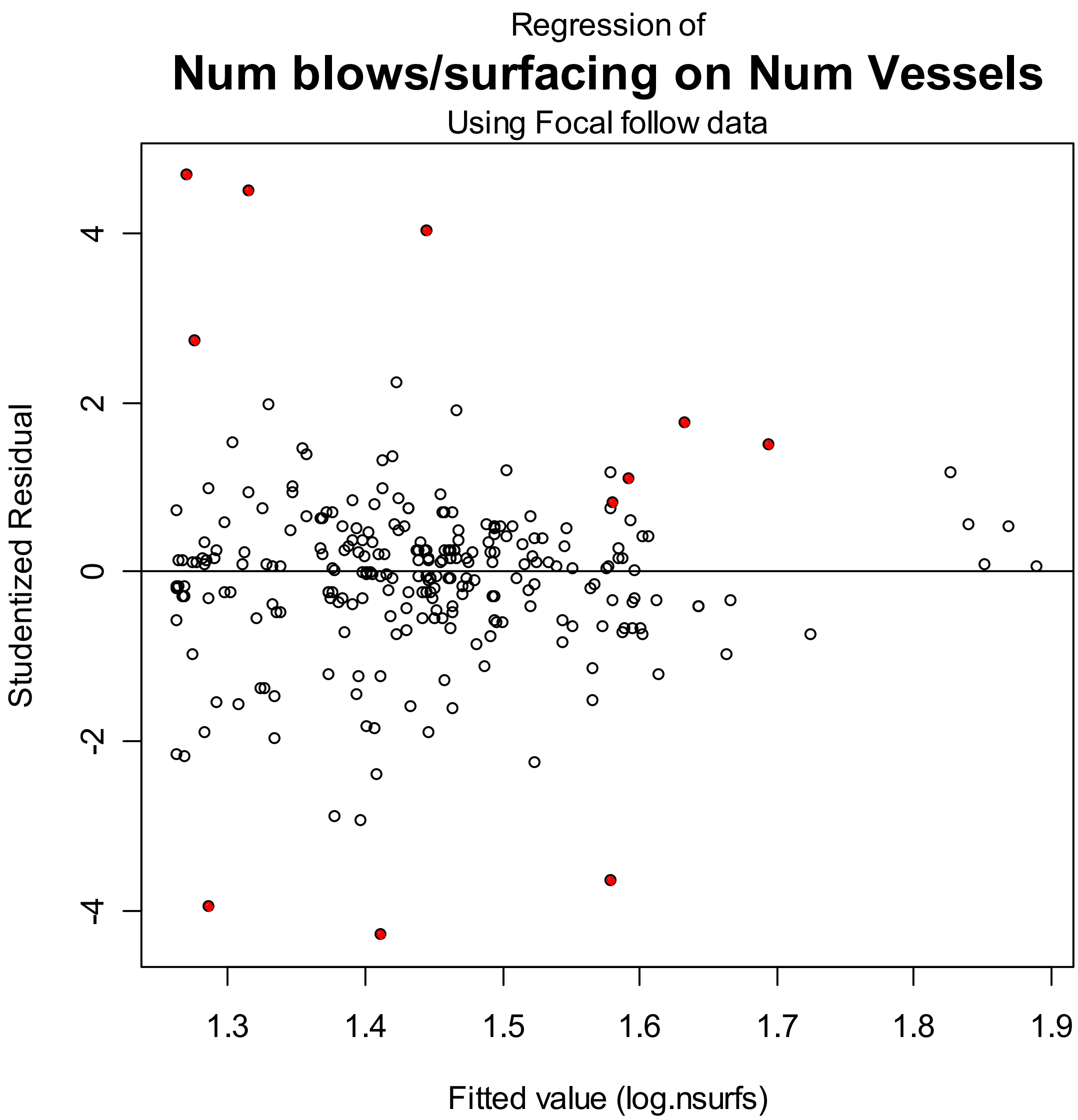

Regression of
Respiration interval on Num Vessels
Using Focal follow data
Studentized Residual
-2
0
2
4
0.25
0.30
0.35
0.40
0.45
0.50
Fitted value (ri)

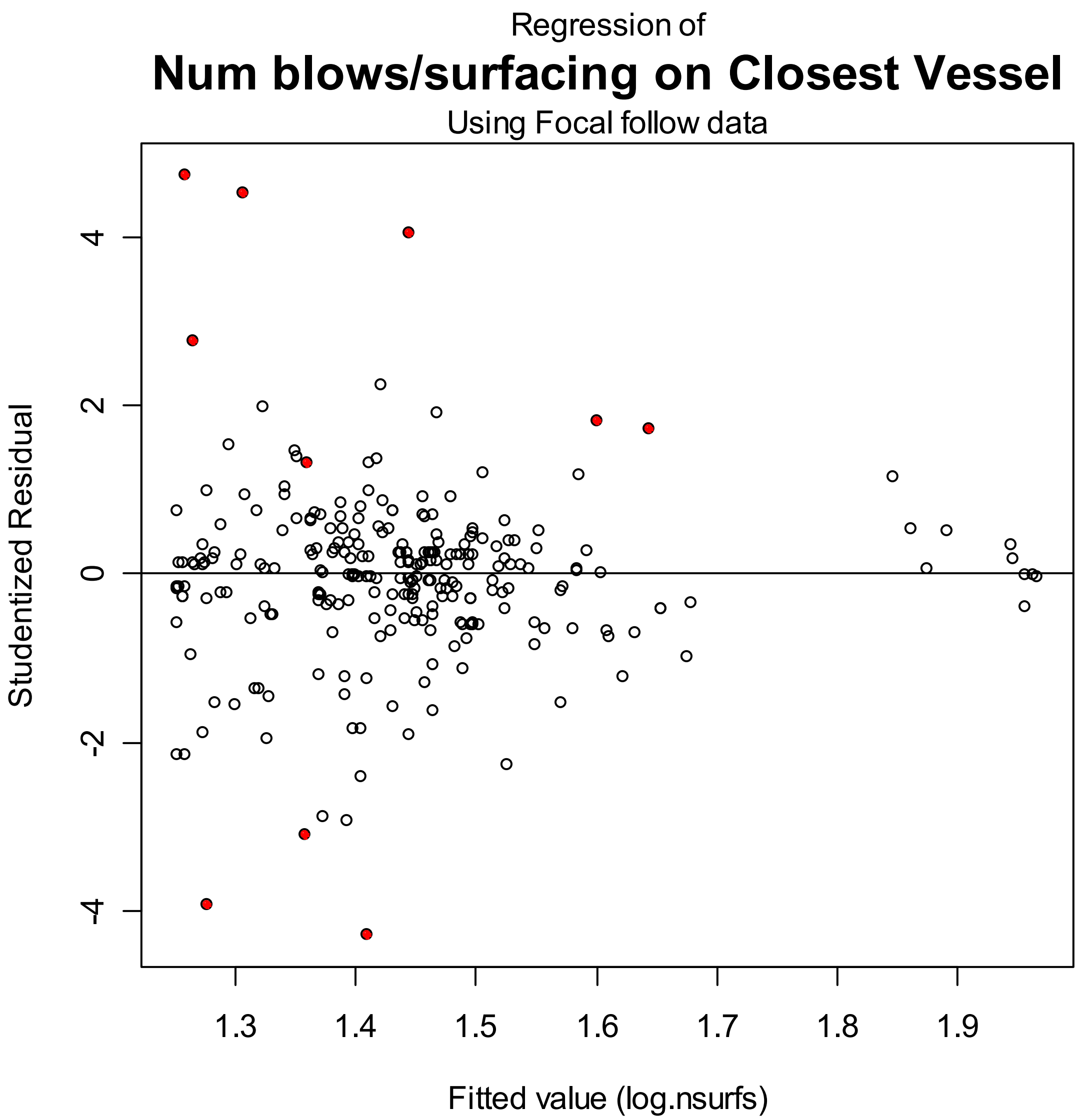

Regression of
Respiration interval on Closest Vessel
Using Focal follow data
Studentized Residual
-2
0
2
4
0.20
0.25
0.30
0.35
0.40
0.45
0.50
Fitted value (ri)

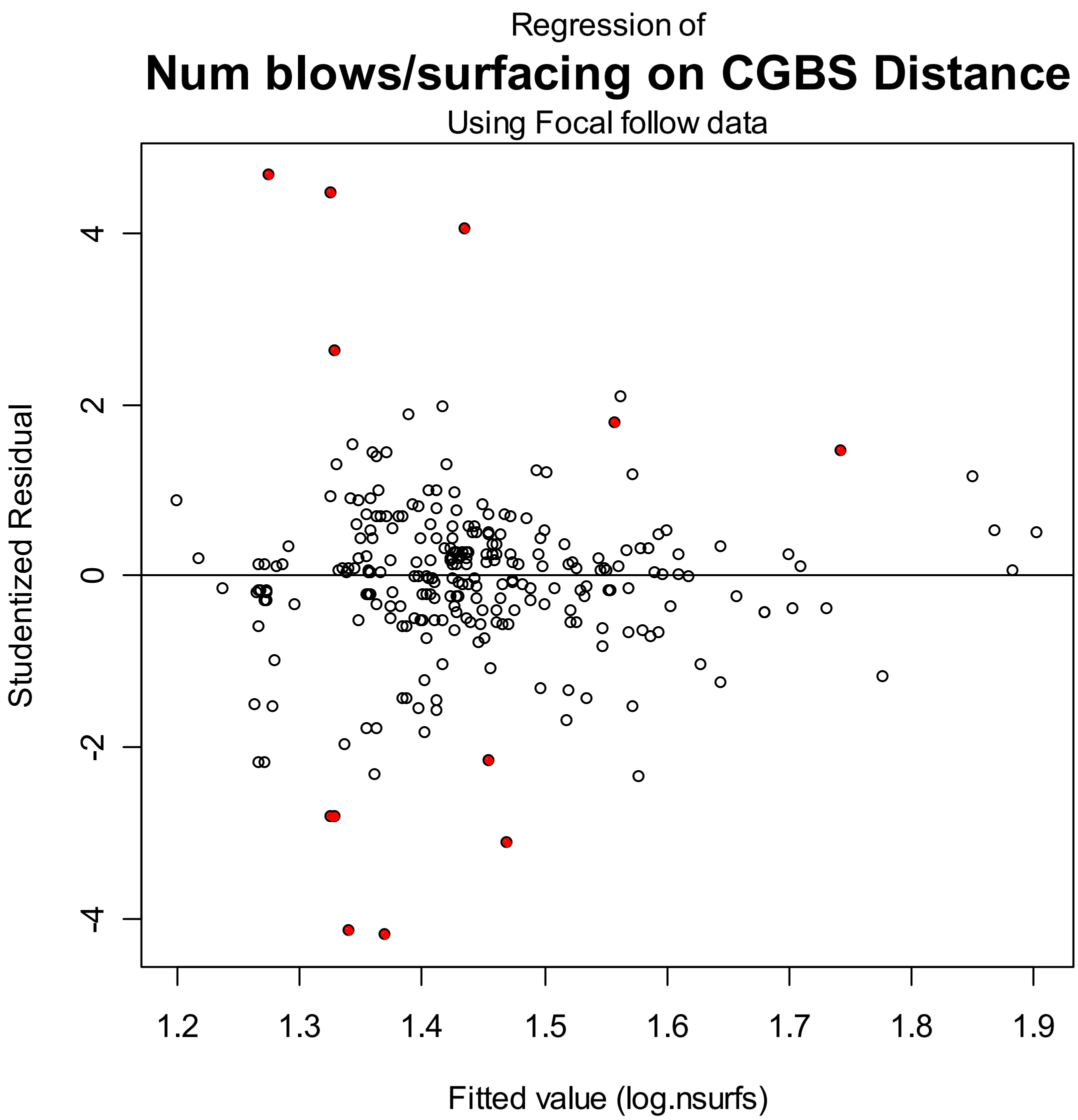

Regression of
Respiration interval on CGBS Distance
Using Focal follow data
Studentized Residual
-2
0
2
4
0.35
0.40
0.45
Fitted value (ri)

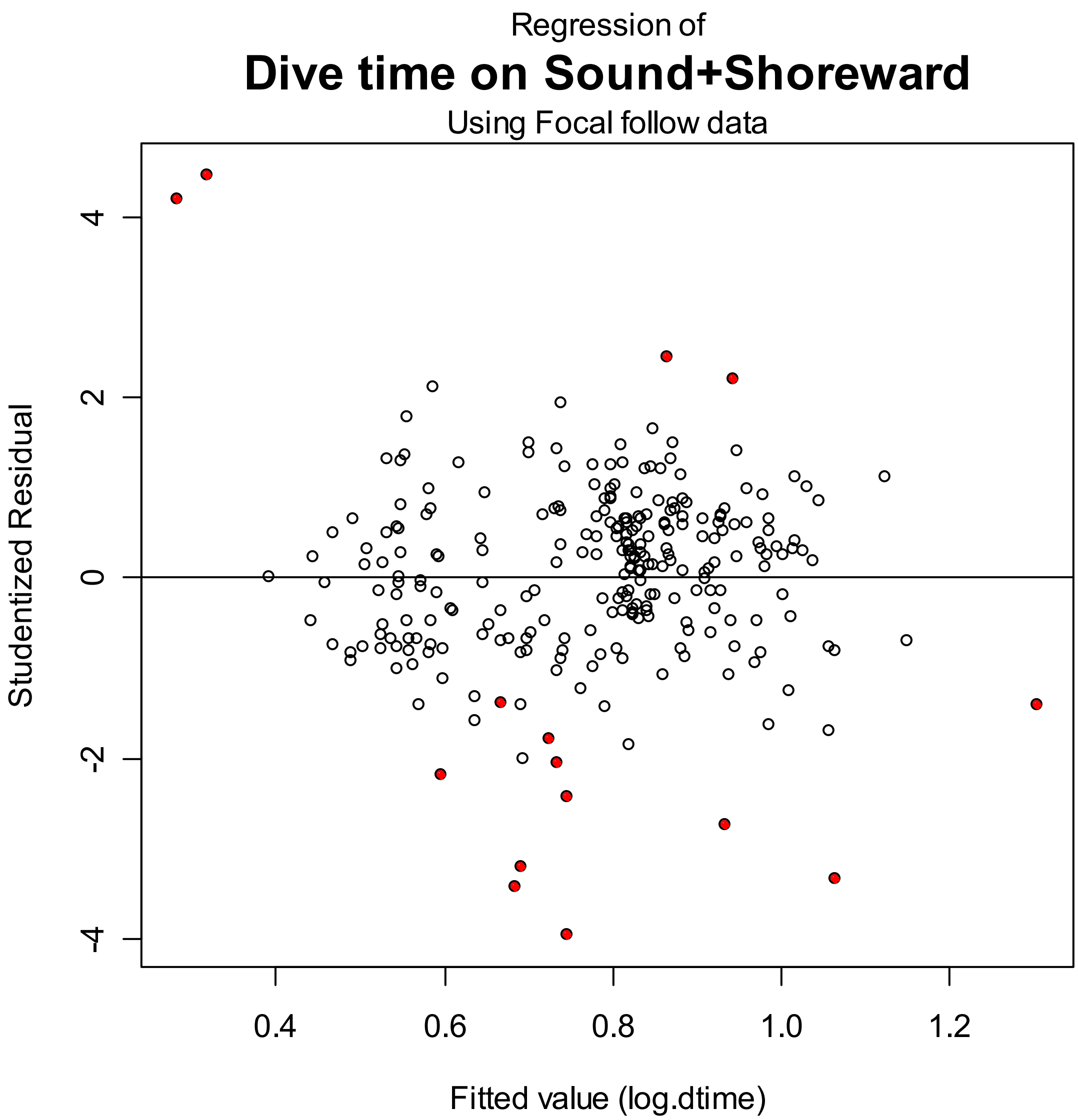

Regression of
Num blows/surfacing on Sound+Shoreward
Using Focal follow data
Studentized Residual
Fitted value (log.nsurfs)
-4
-2
0
2
4
1.2
1.4
1.6
1.8
2.0

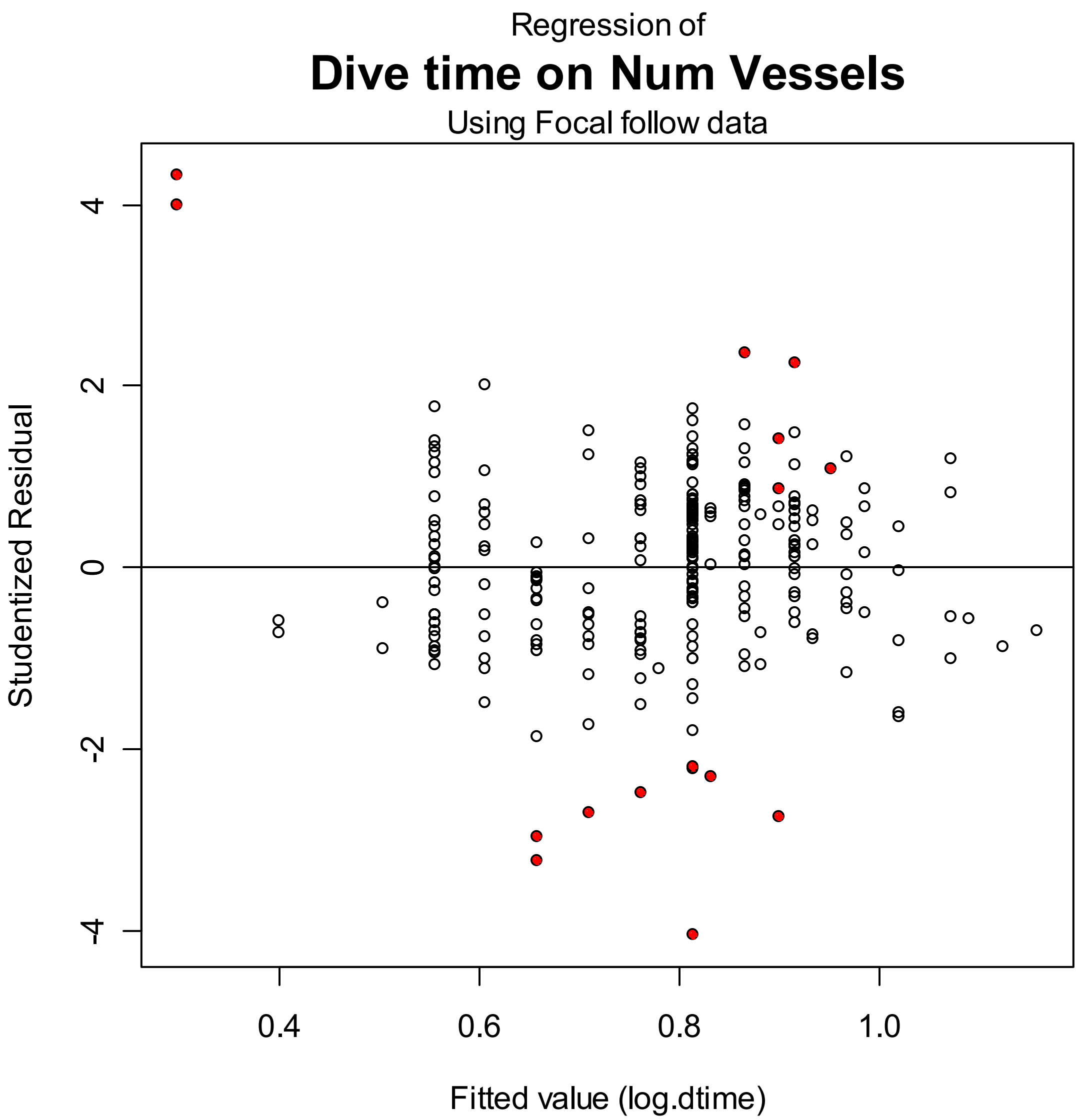

Regression of
Num blows/surfacing on Sound level
Using Focal follow data
Studentized Residual
Fitted value (log.nsurfs)
4
2
0
-2
-4
1.2
1.4
1.6
1.8
2.0

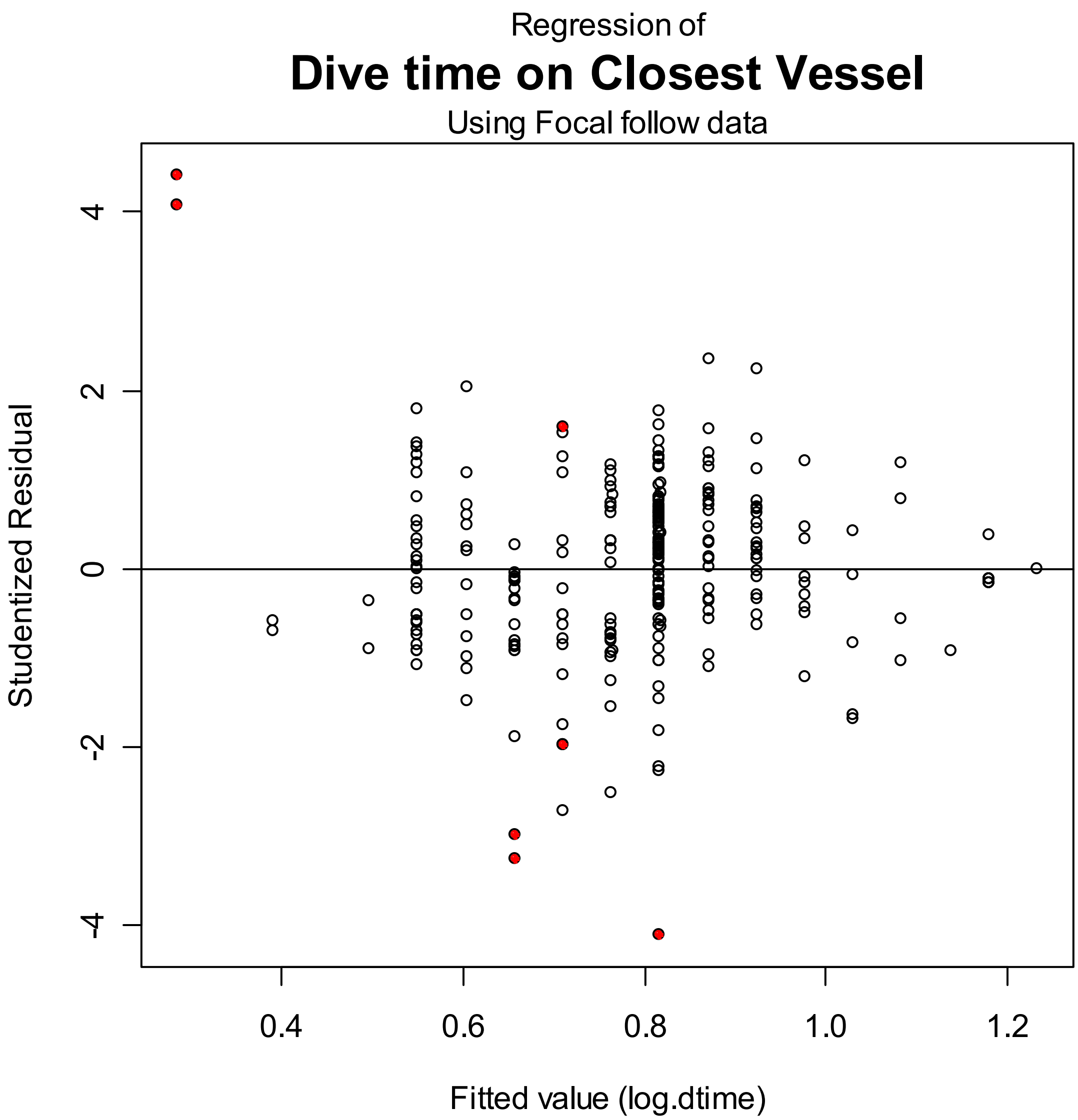

Regression of
Num blows/surfacing on Num Vessels
Using Focal follow data
Studentized Residual
Fitted value (log.nsurfs)
4
2
0
-2
-4
1.3
1.4
1.5
1.6
1.7
1.8
1.9

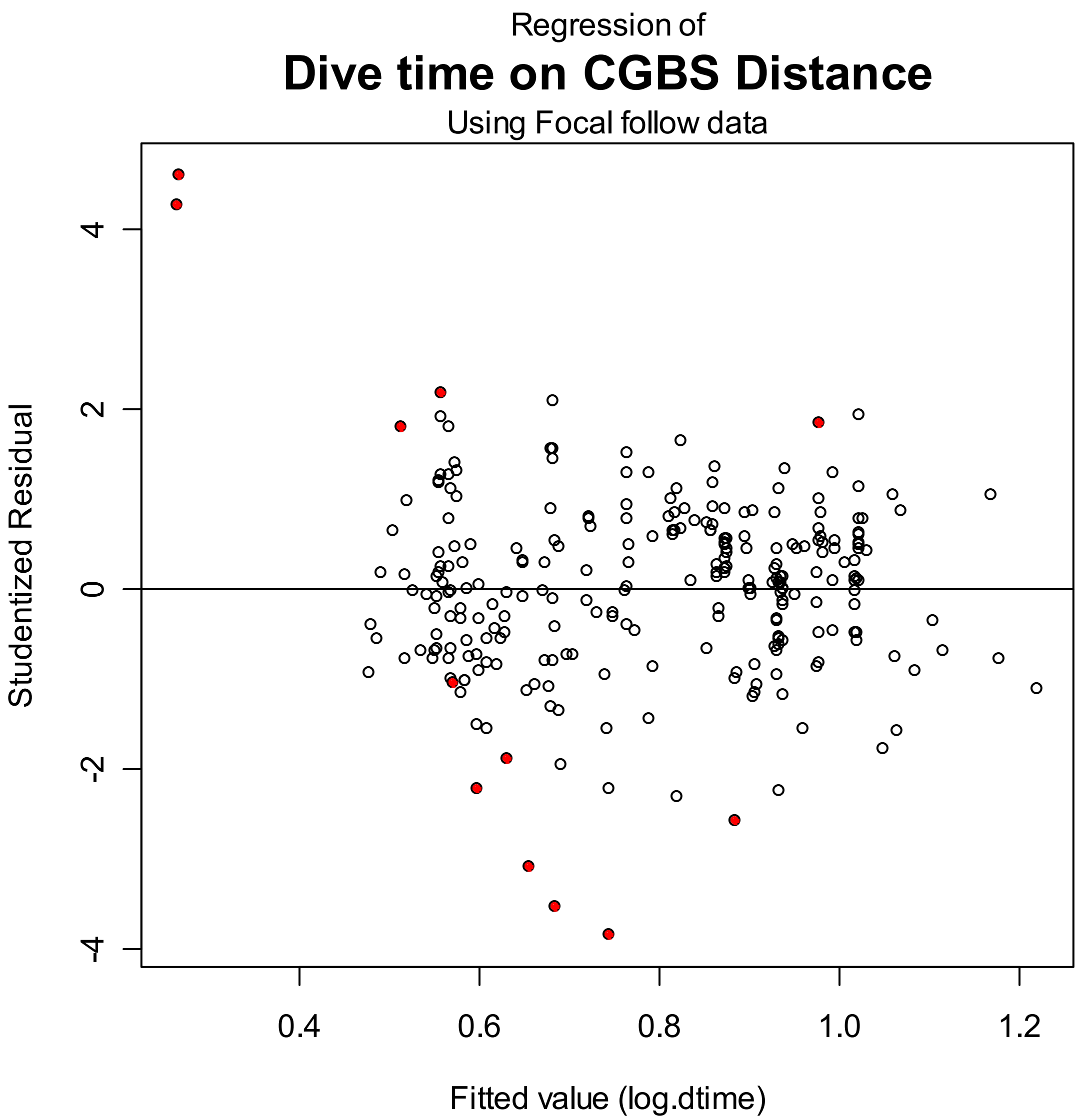

Regression of
Num blows/surfacing on Closest Vessel
Using Focal follow data
Studentized Residual
4
2
0
-2
-4
1.3
1.4
1.5
1.6
1.7
1.8
1.9
Fitted value (log.nsurfs)


Regression of
Num blows/surfacing on CGBS Distance
Using Focal follow data
Studentized Residual
4
2
0
-2
-4
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
Fitted value (log.nsurfs)

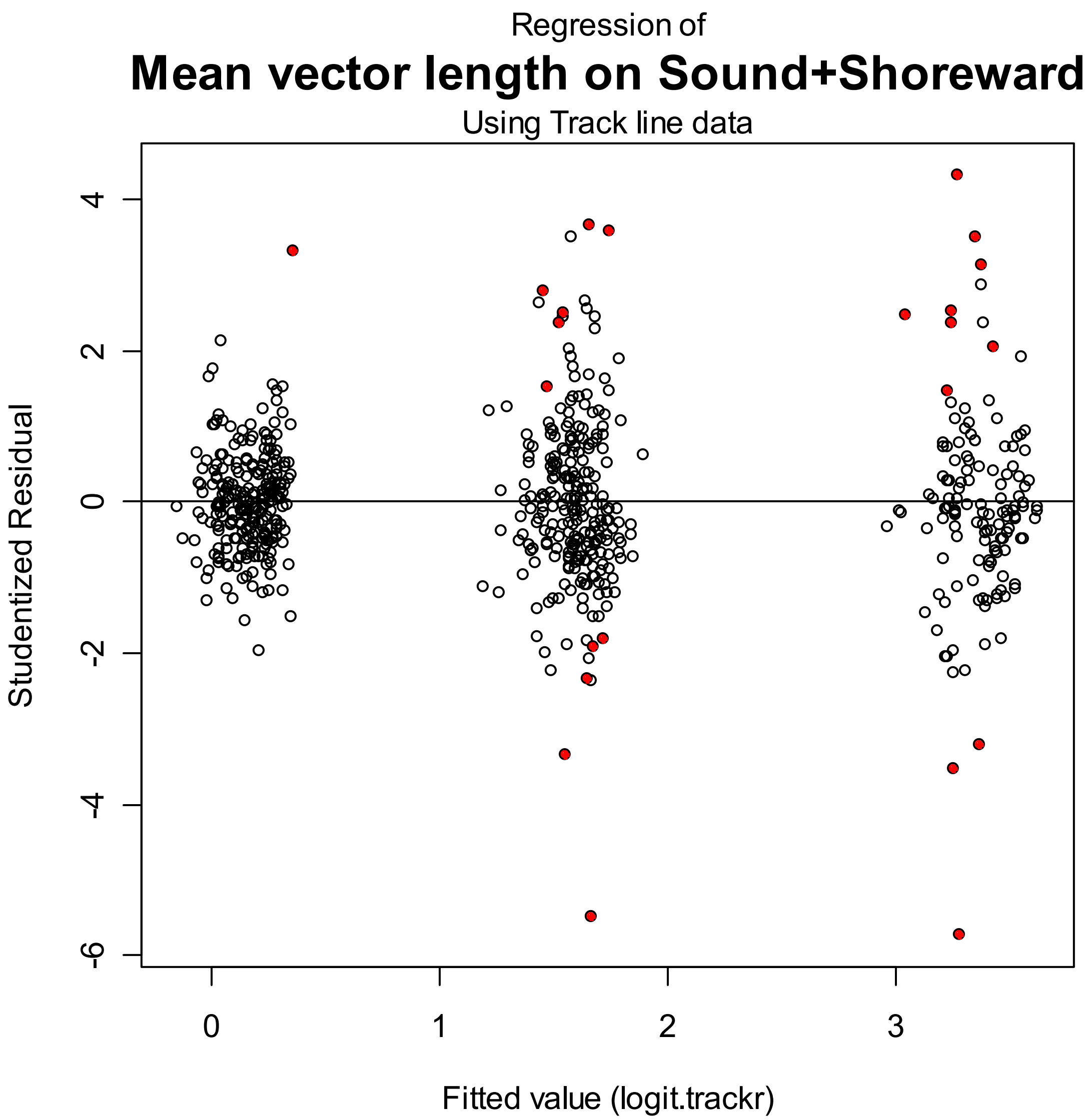

Regression of
Dive time on Sound+Shoreward
Using Focal follow data
Studentized Residual
4
2
0
-2
-4
0.4
0.6
0.8
1.0
1.2
Fitted value (log.dtime)

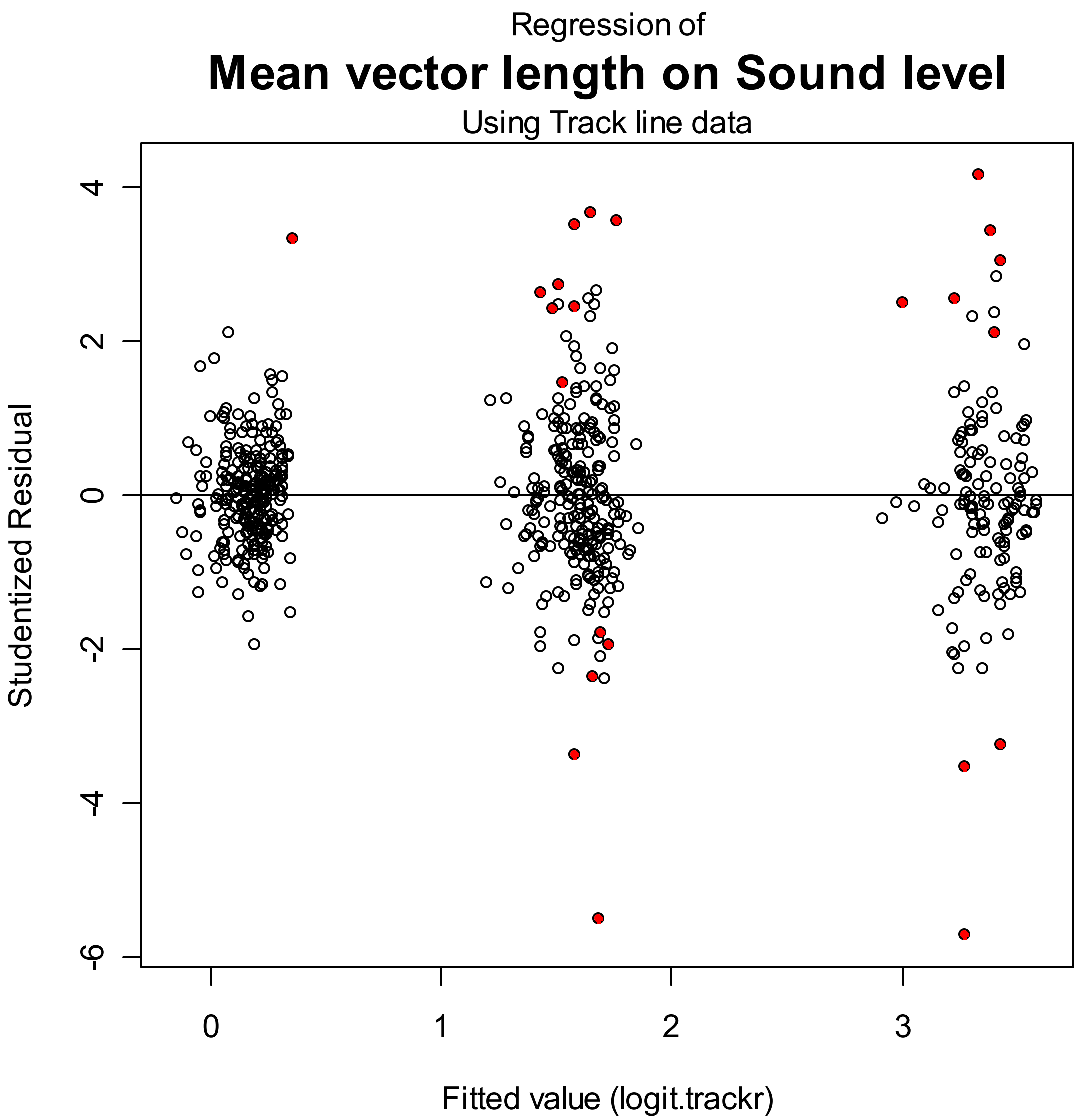

Regression of
Dive time on Num Vessels
Using Focal follow data
Studentized Residual
4
2
0
-2
-4
0.4
0.6
0.8
1.0
Fitted value (log.dtime)

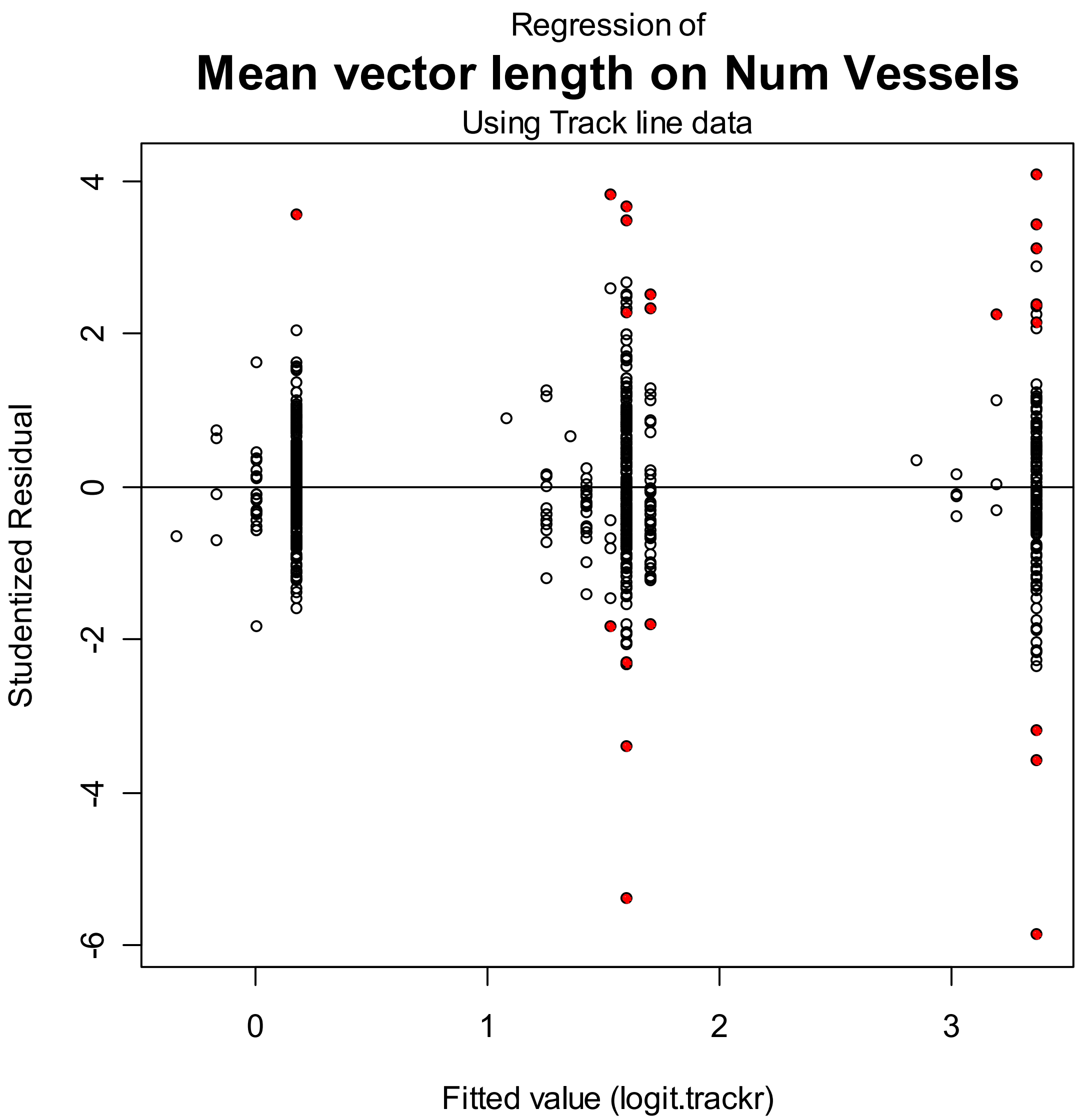

Regression of
Dive time on Closest Vessel
Using Focal follow data
Studentized Residual
Fitted value (log.dtime)
4
2
0
-2
-4
0.4
0.6
0.8
1.0
1.2

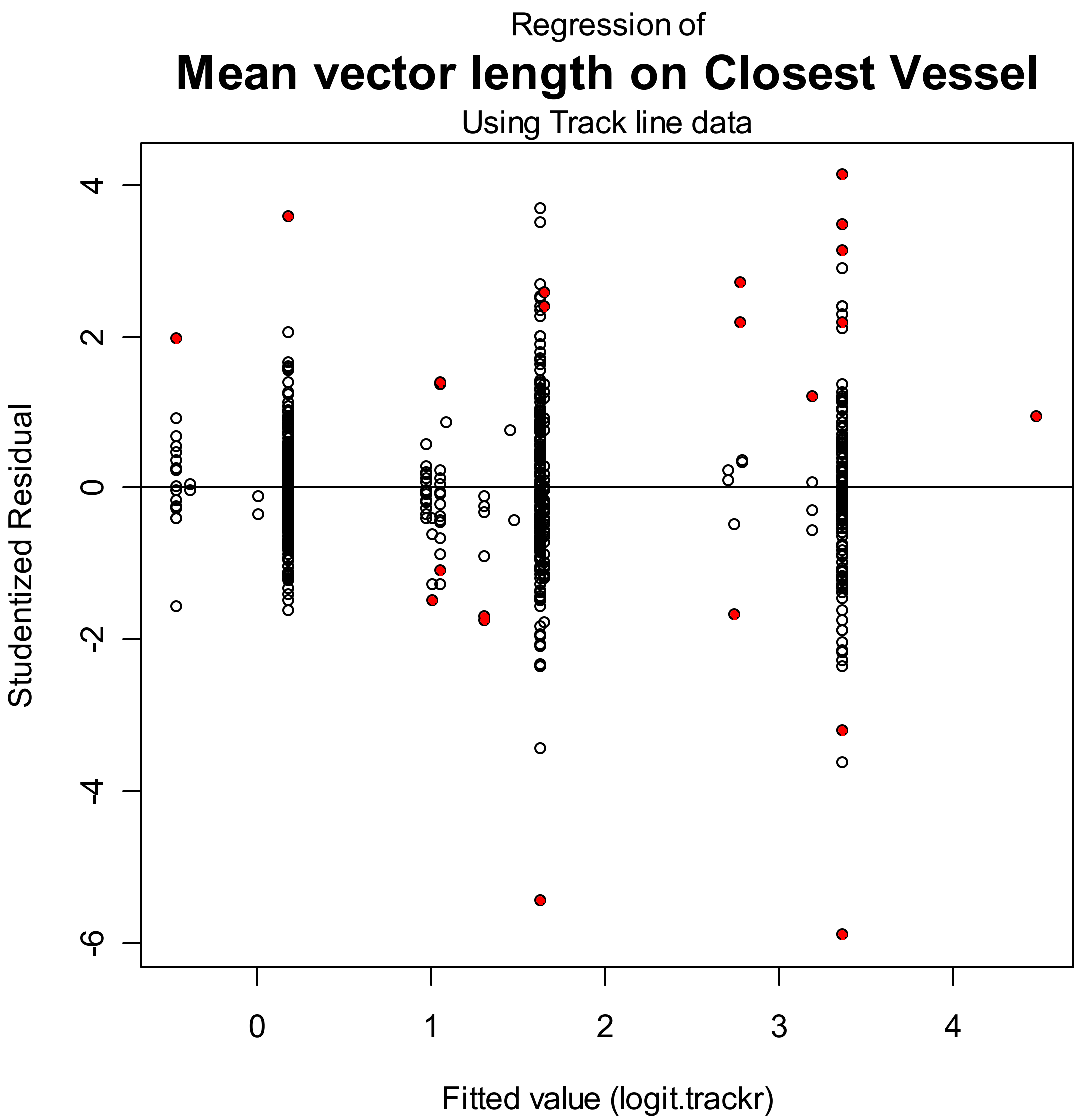


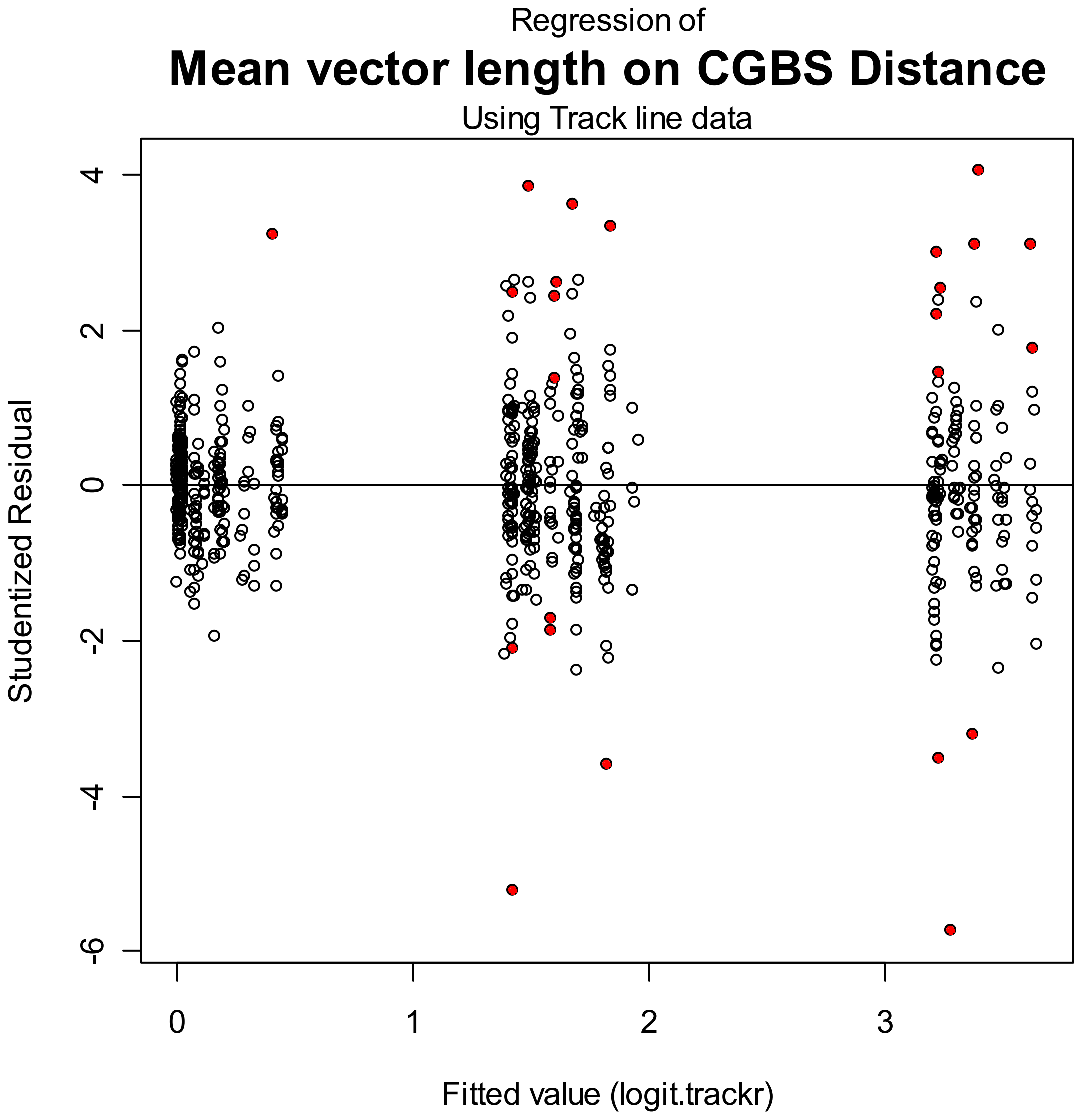
Regression of
Dive time on CGBS Distance
Using Focal follow data
Studentized Residual
Fitted value (log.dtime)
4
2
0
-2
-4
0.4
0.6
0.8
1.0
1.2

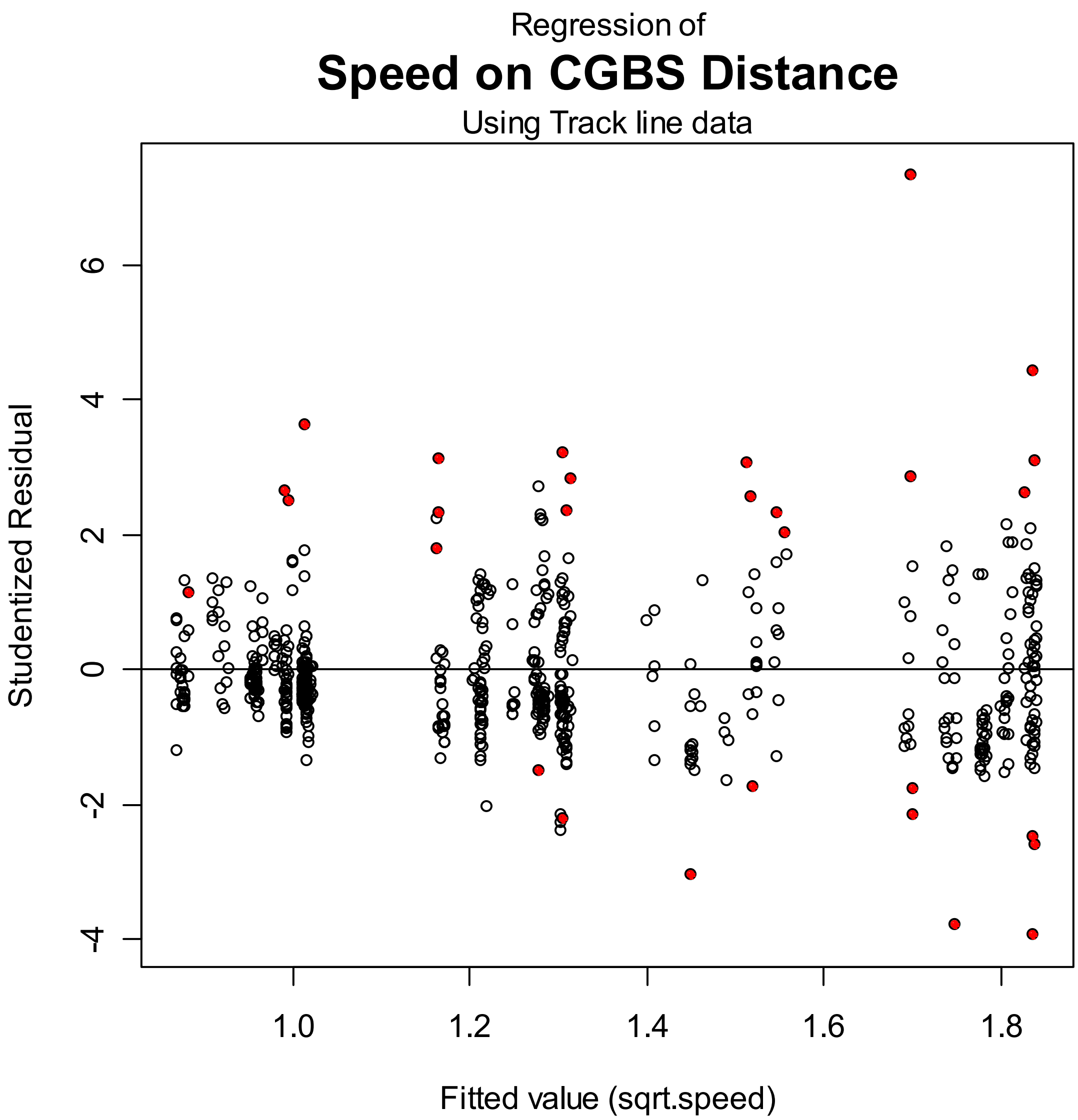

Regression of
Mean vector length on Sound+Shoreward
Using Track line data
Studentized Residual
Fitted value (logit.trackr)
4
2
0
-2
-4
-6
0
1
2
3

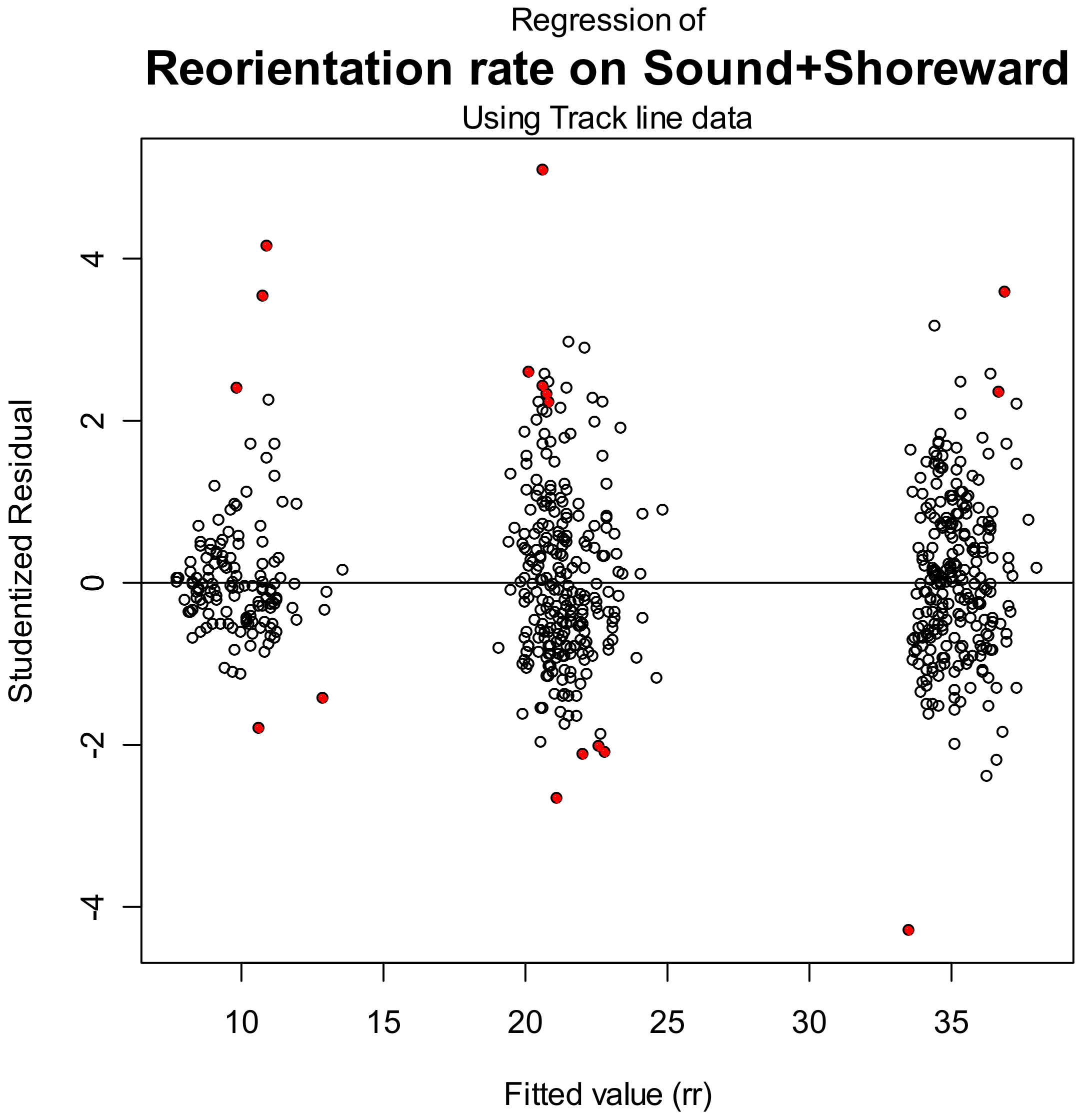

Regression of
Mean vector length on Sound level
Using Track line data
Studentized Residual
4
2
0
-2
-4
-6
0
1
2
3
Fitted value (logit.trackr)

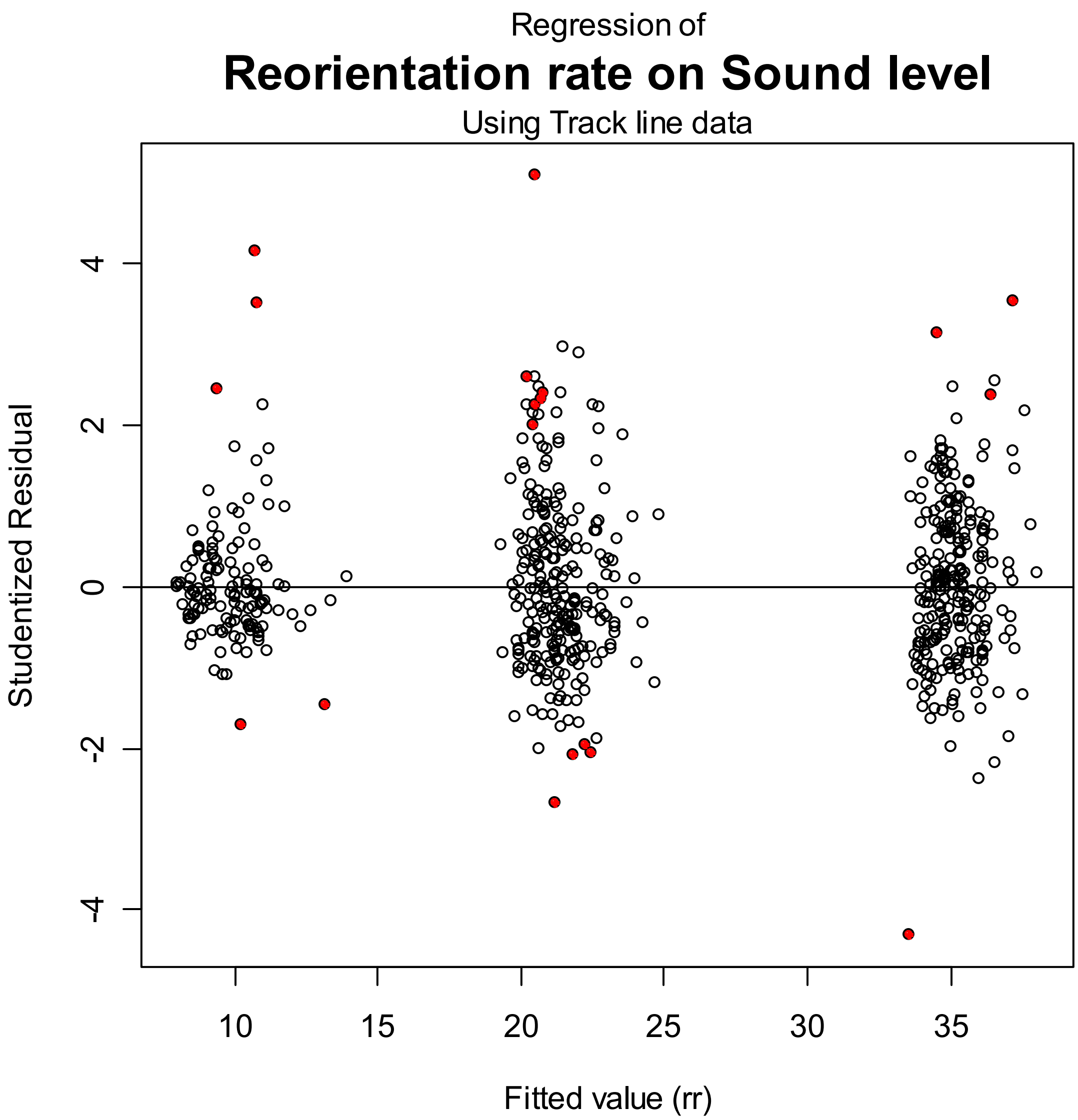

Regression of
Mean vector length on Num Vessels
Using Track line data
Studentized Residual
Fitted value (logit.trackr)
4
2
0
-2
-4
-6
0
1
2
3

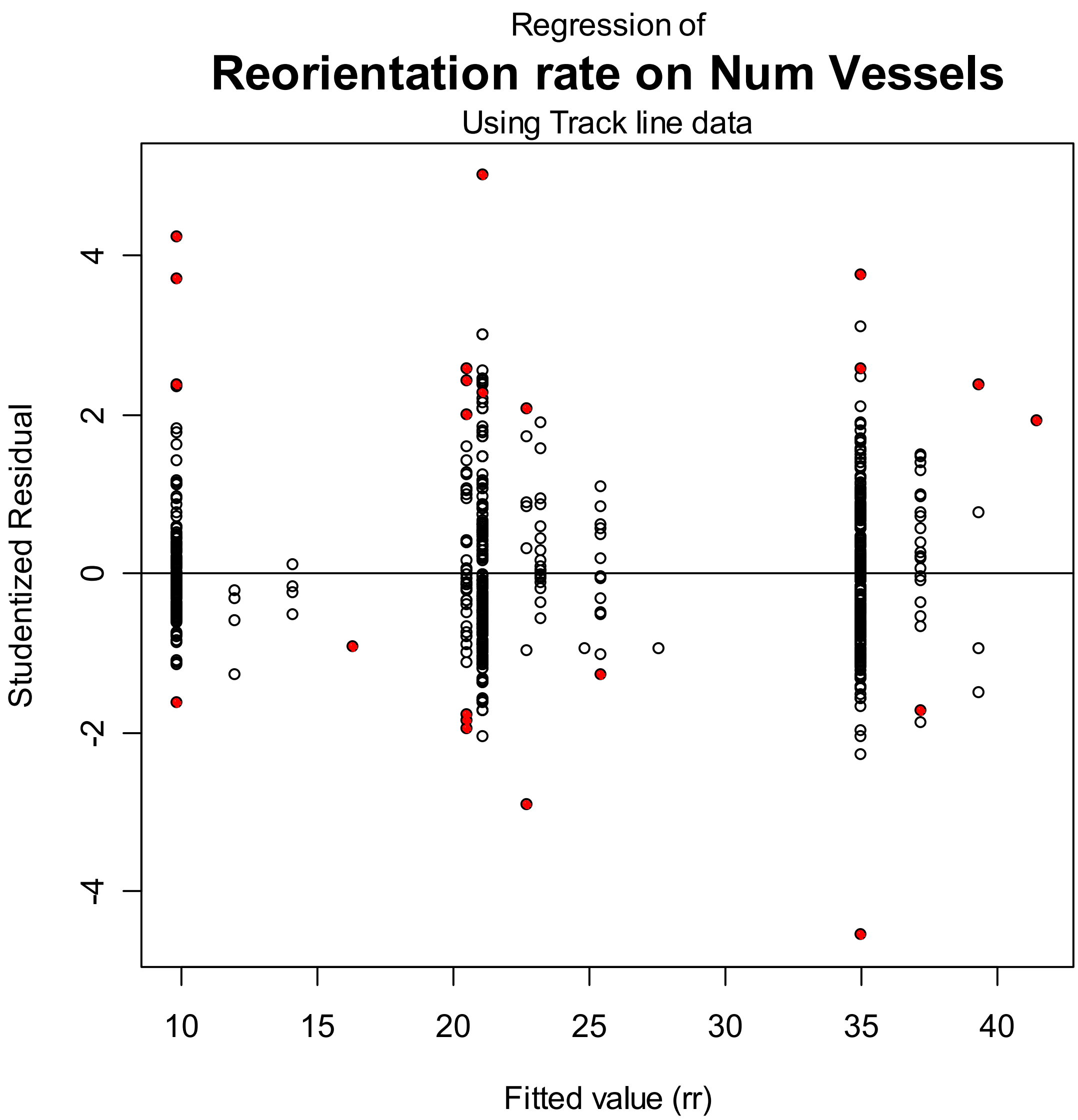

Regression of
Mean vector length on Closest Vessel
Using Track line data
Studentized Residual
Fitted value (logit.trackr)
4
2
0
-2
-4
-6
0
1
2
3
4

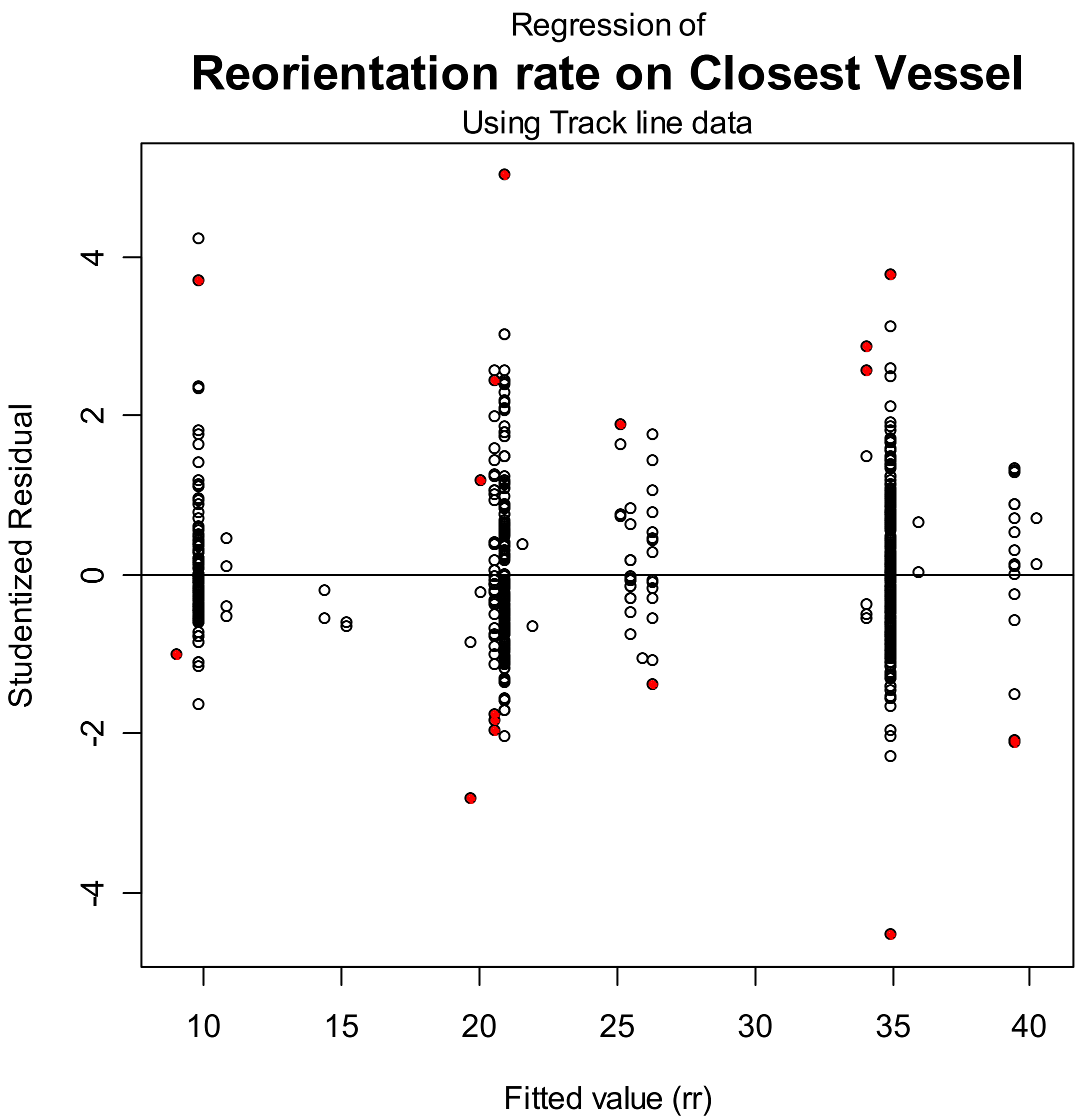

Regression of
Mean vector length on CGBS Distance
Using Track line data
Studentized Residual
4
2
0
-2
-4
-6
0
1
2
3
Fitted value (logit.trackr)

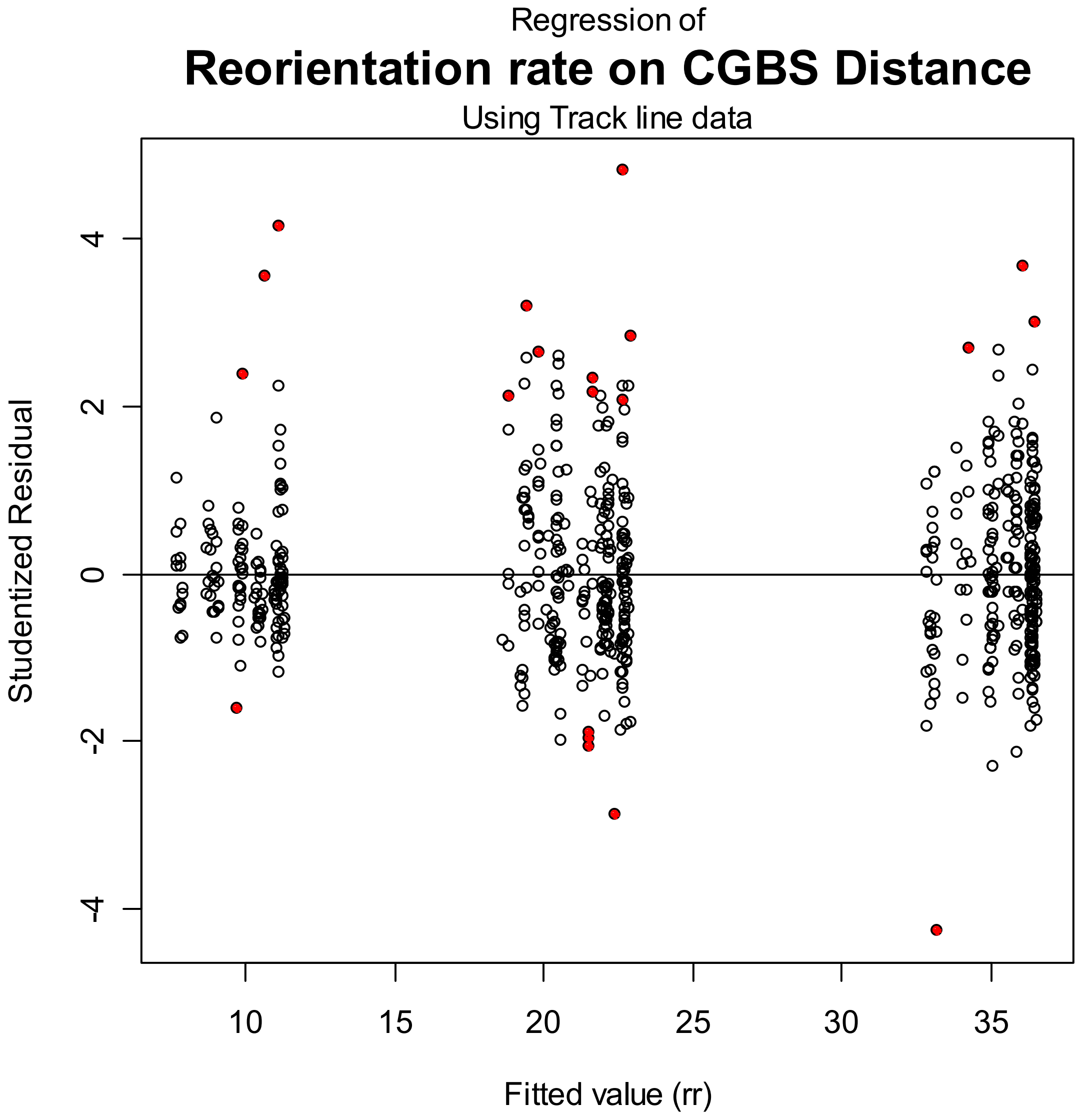

Regression of
Speed on CGBS Distance
Using Track line data
Studentized Residual
Fitted value (sqrt.speed)
6
4
2
0
-2
-4
1.0
1.2
1.4
1.6
1.8

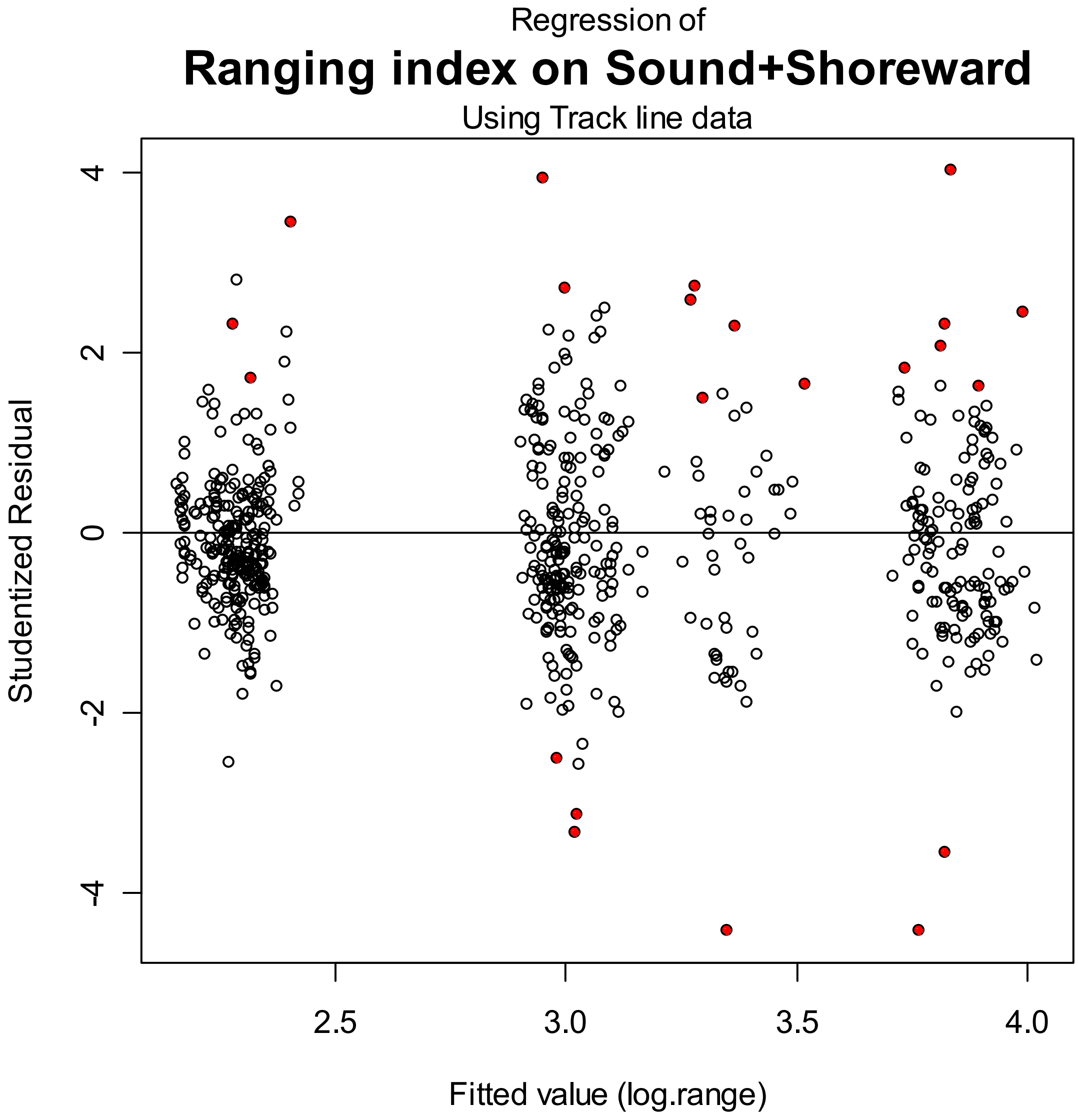

Regression of
Reorientation rate on Sound+Shoreward
Using Track line data
Studentized Residual
Fitted value (rr)
-4
-2
0
2
4
10
15
20
25
30
35

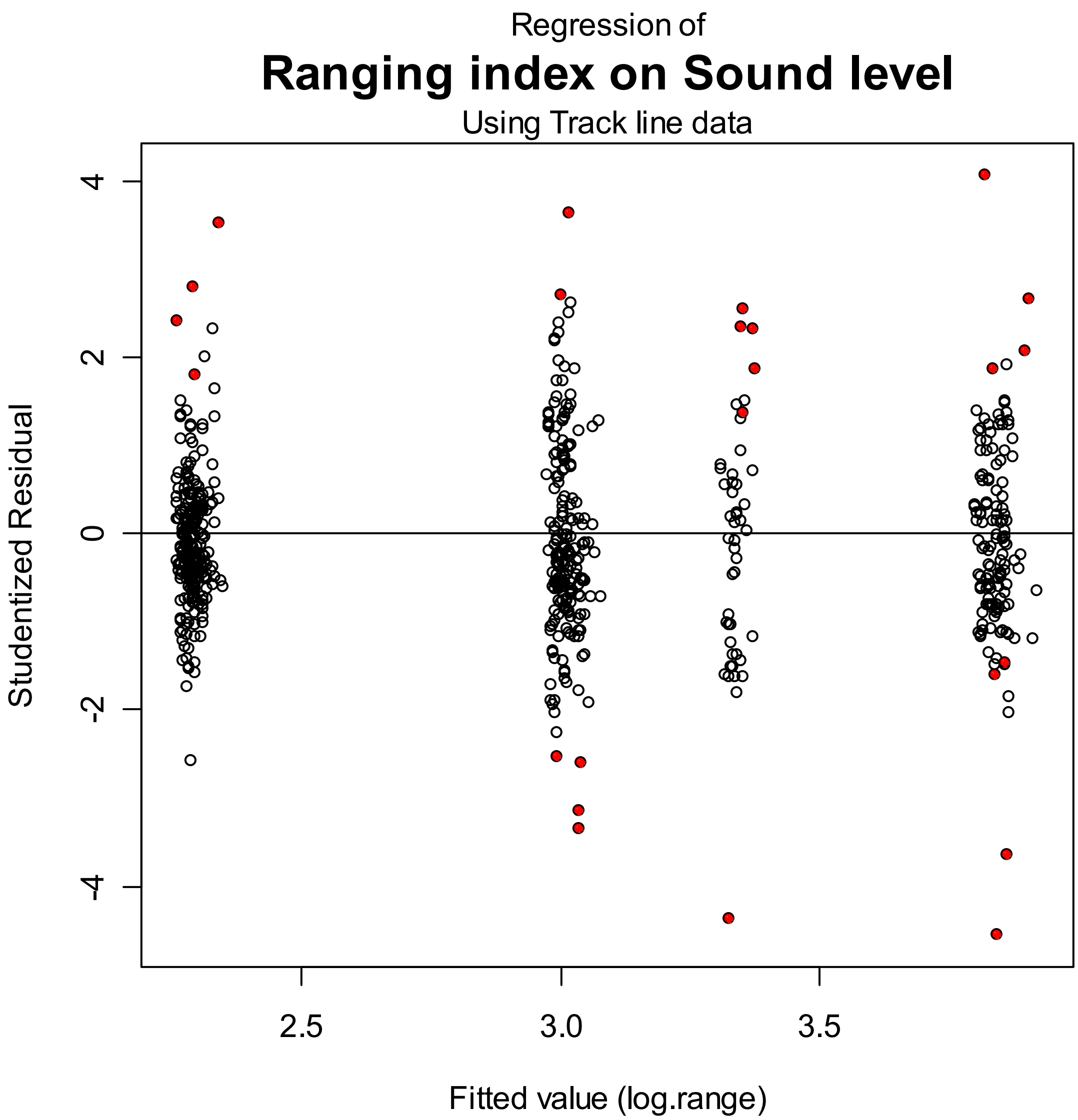

Regression of
Reorientation rate on Sound level
Using Track line data
Studentized Residual
-4
-2
0
2
4
10
15
20
25
30
35
Fitted value (rr)

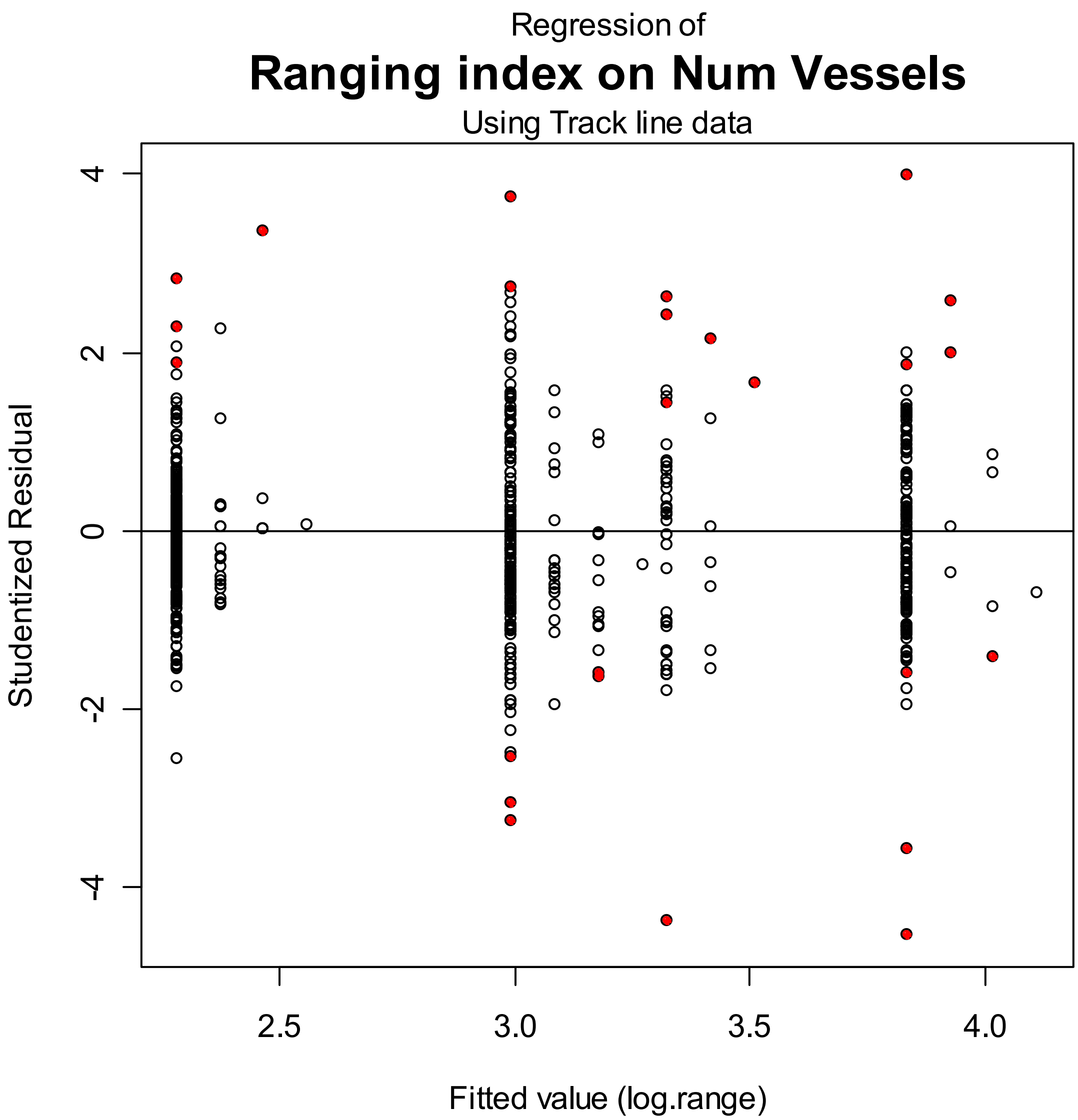

Regression of
Reorientation rate on Num Vessels
Using Track line data
Studentized Residual
Fitted value (rr)
-4
-2
0
2
4
10
15
20
25
30
35
40

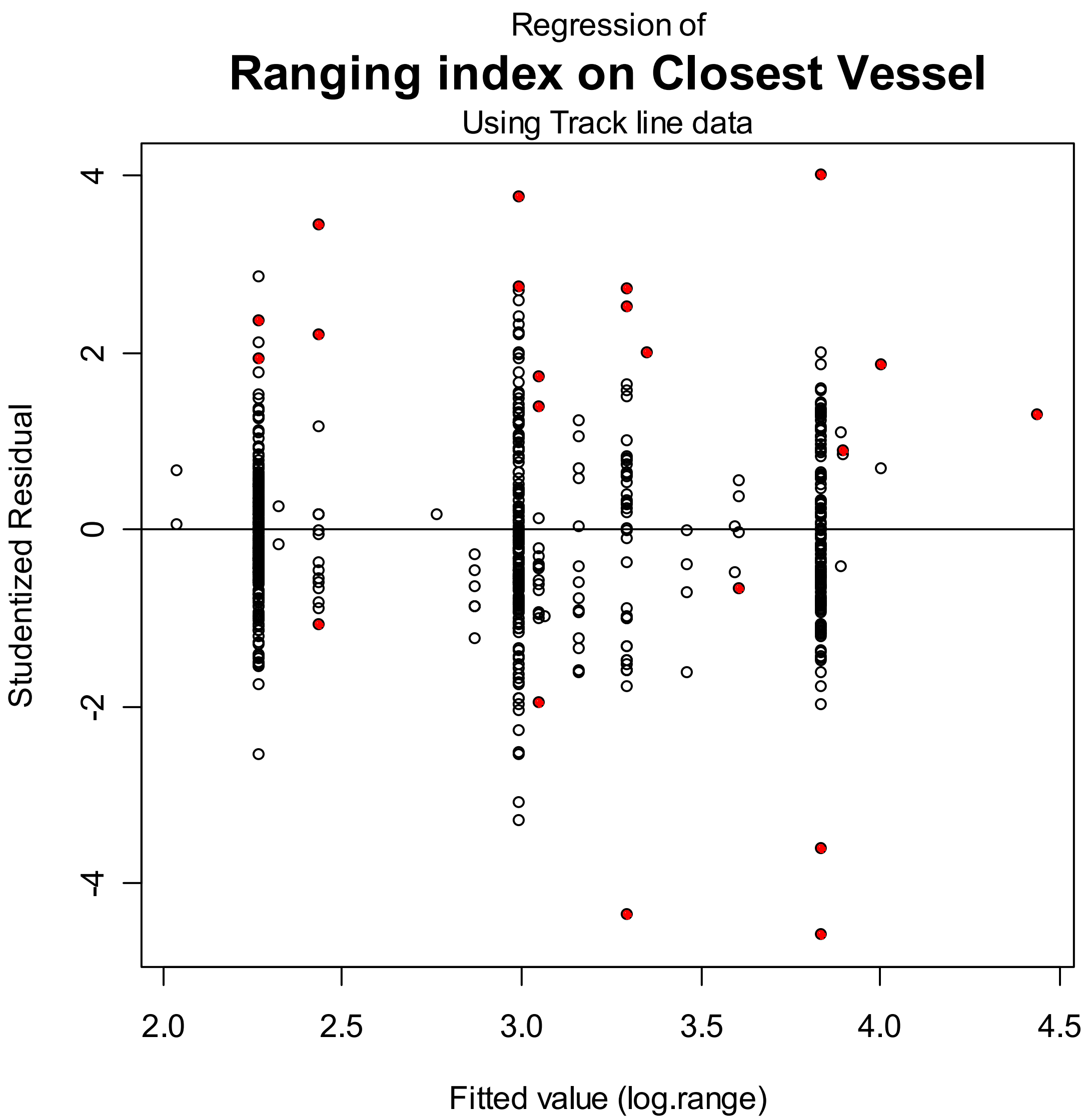

Regression of
Reorientation rate on Closest Vessel
Using Track line data
Studentized Residual
4
2
0
-2
-4
10
15
20
25
30
35
40
Fitted value (rr)

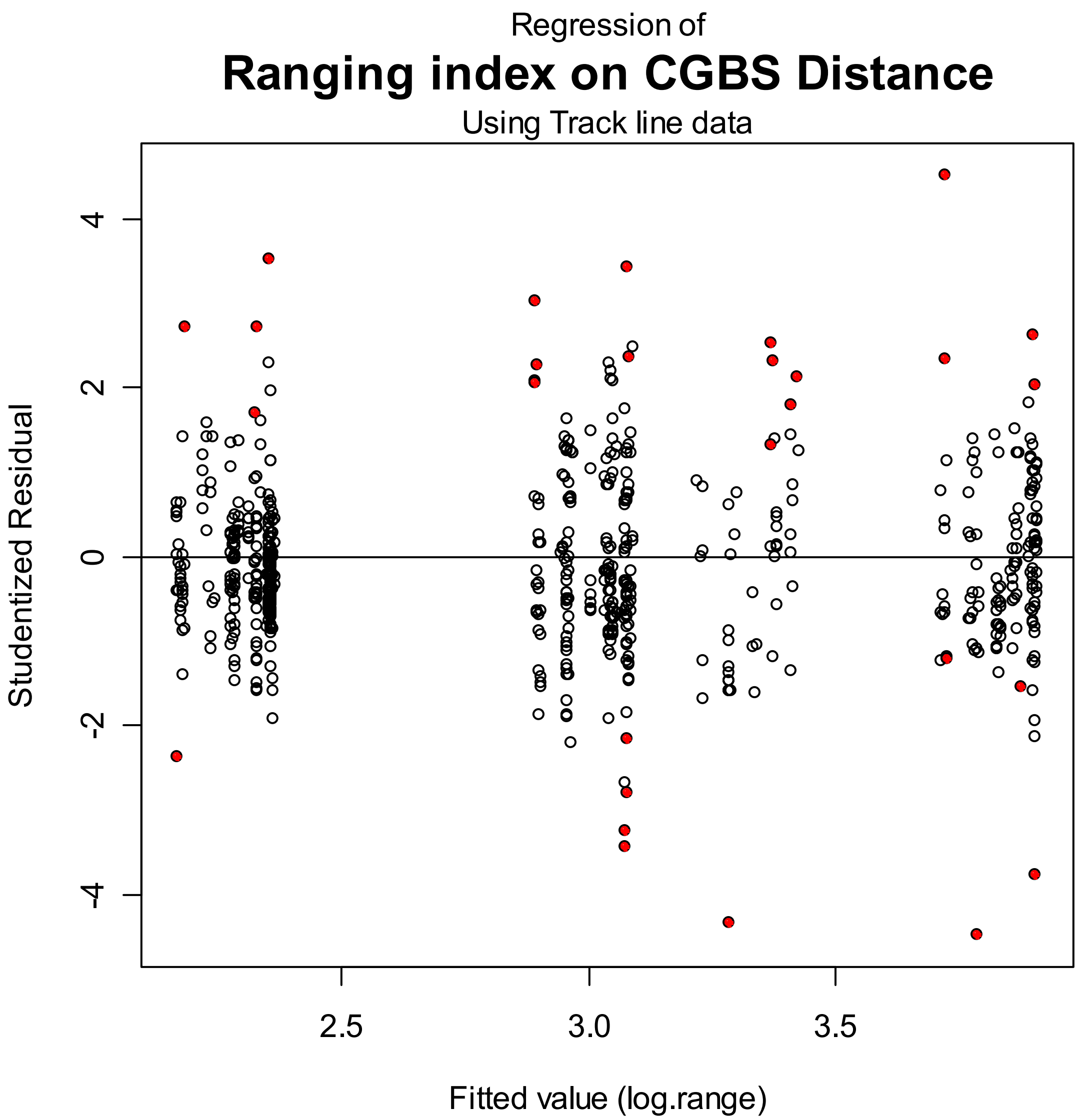

Regression of
Reorientation rate on CGBS Distance
Using Track line data
Studentized Residual
4
2
0
-2
-4
10
15
20
25
30
35
Fitted value (rr)

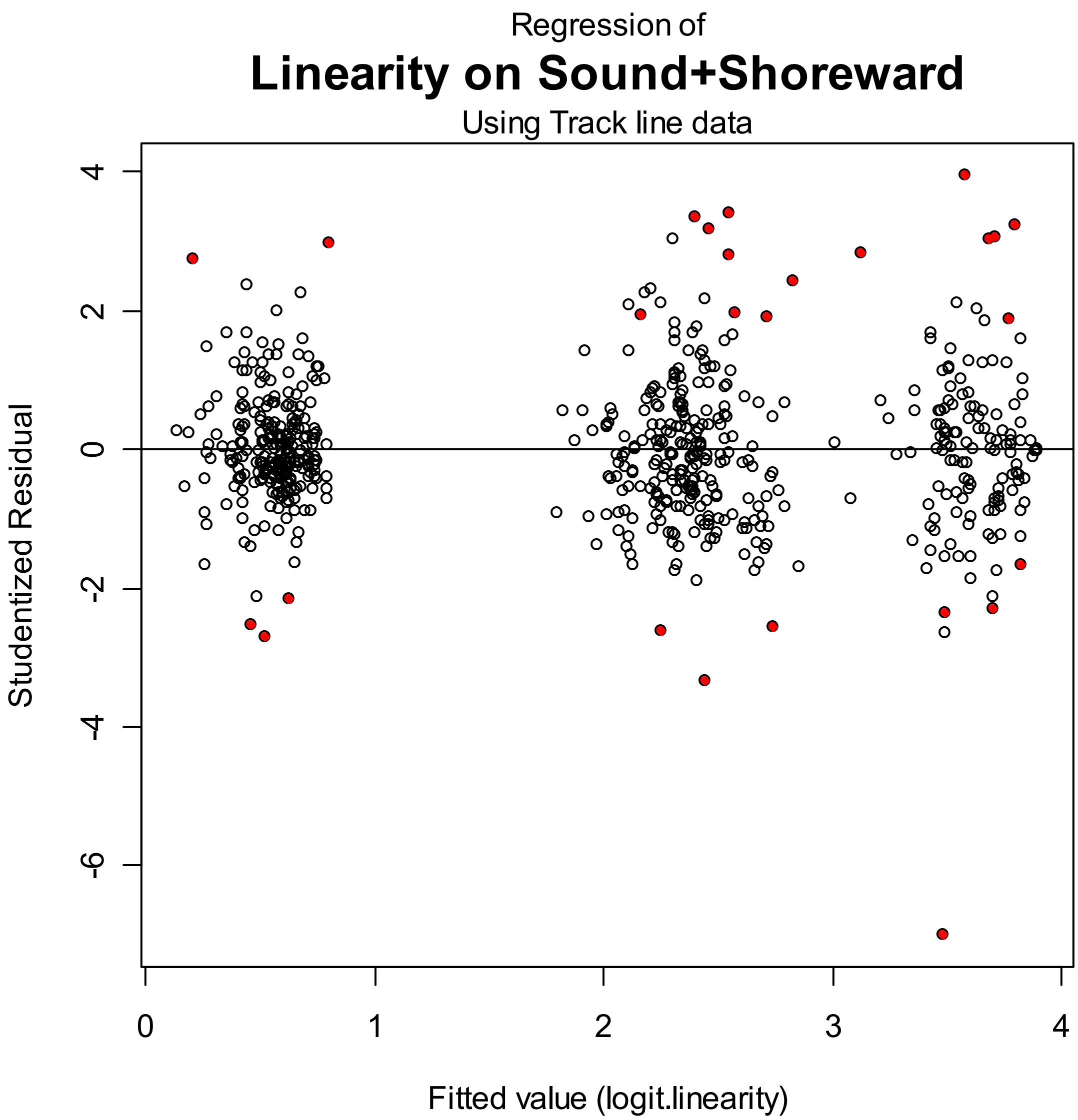

Regression of
Ranging index on Sound+Shoreward
Using Track line data
Studentized Residual
4
2
0
-2
-4
2.5
3.0
3.5
4.0
Fitted value (log.range)

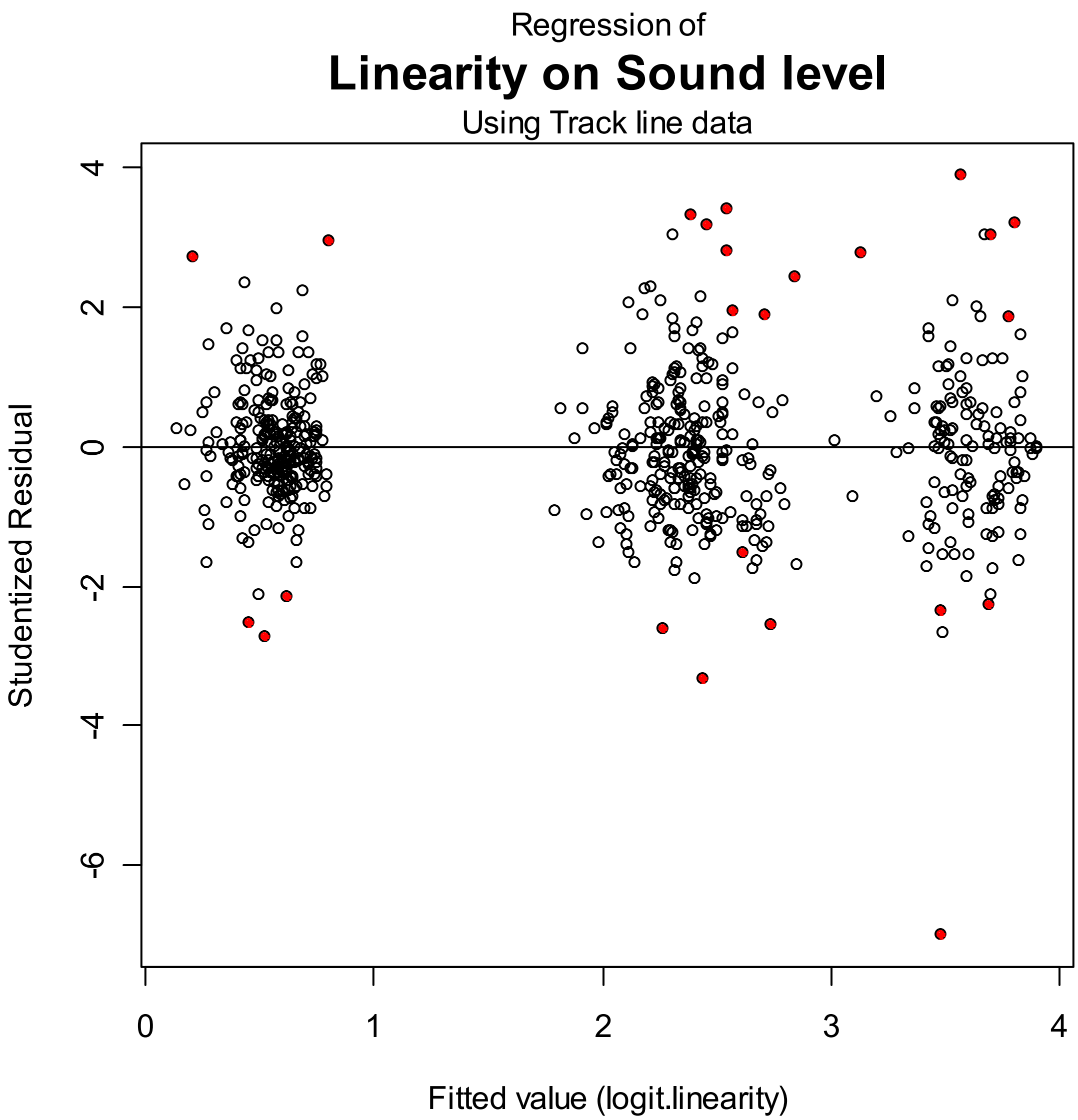

Regression of
Ranging index on Sound level
Using Track line data
Studentized Residual
4
2
0
-2
-4
2.5
3.0
3.5
Fitted value (log.range)

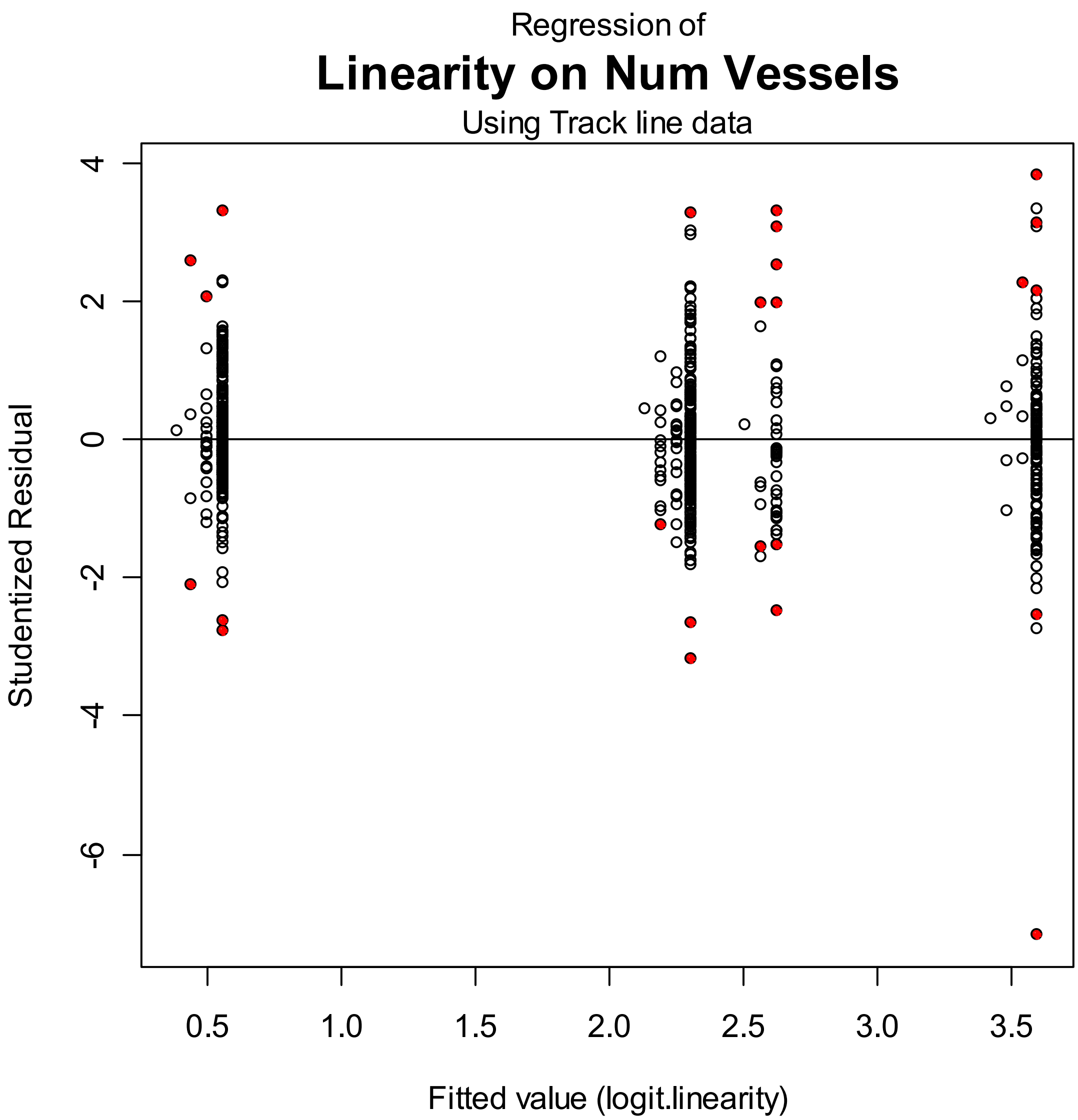

Regression of
Ranging index on Num Vessels
Using Track line data
Studentized Residual
4
2
0
-2
-4
2.5
3.0
3.5
4.0
Fitted value (log.range)

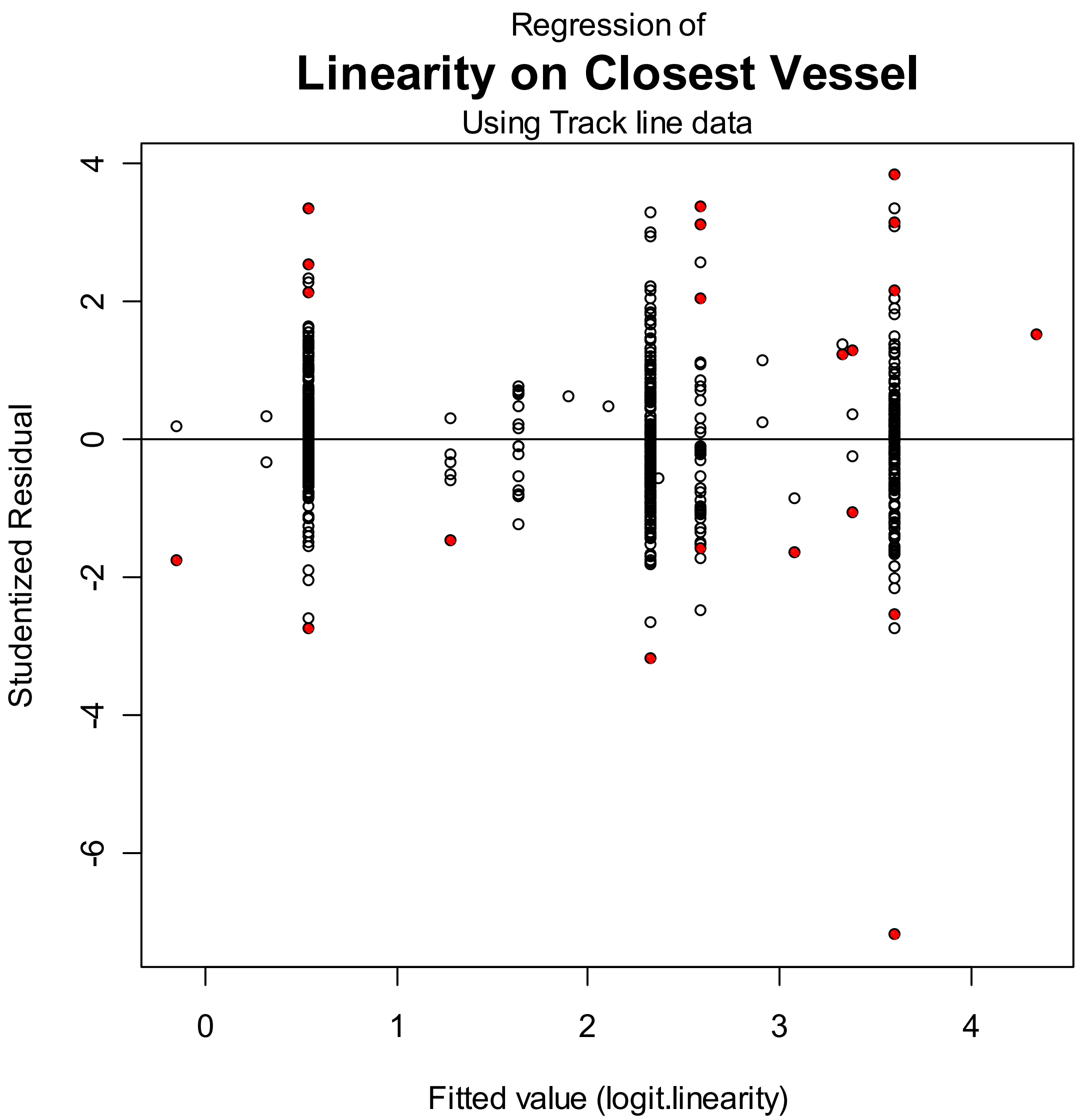

Regression of
Ranging index on Closest Vessel
Using Track line data
Studentized Residual
4
2
0
-2
-4
2.0
2.5
3.0
3.5
4.0
4.5
Fitted value (log.range)

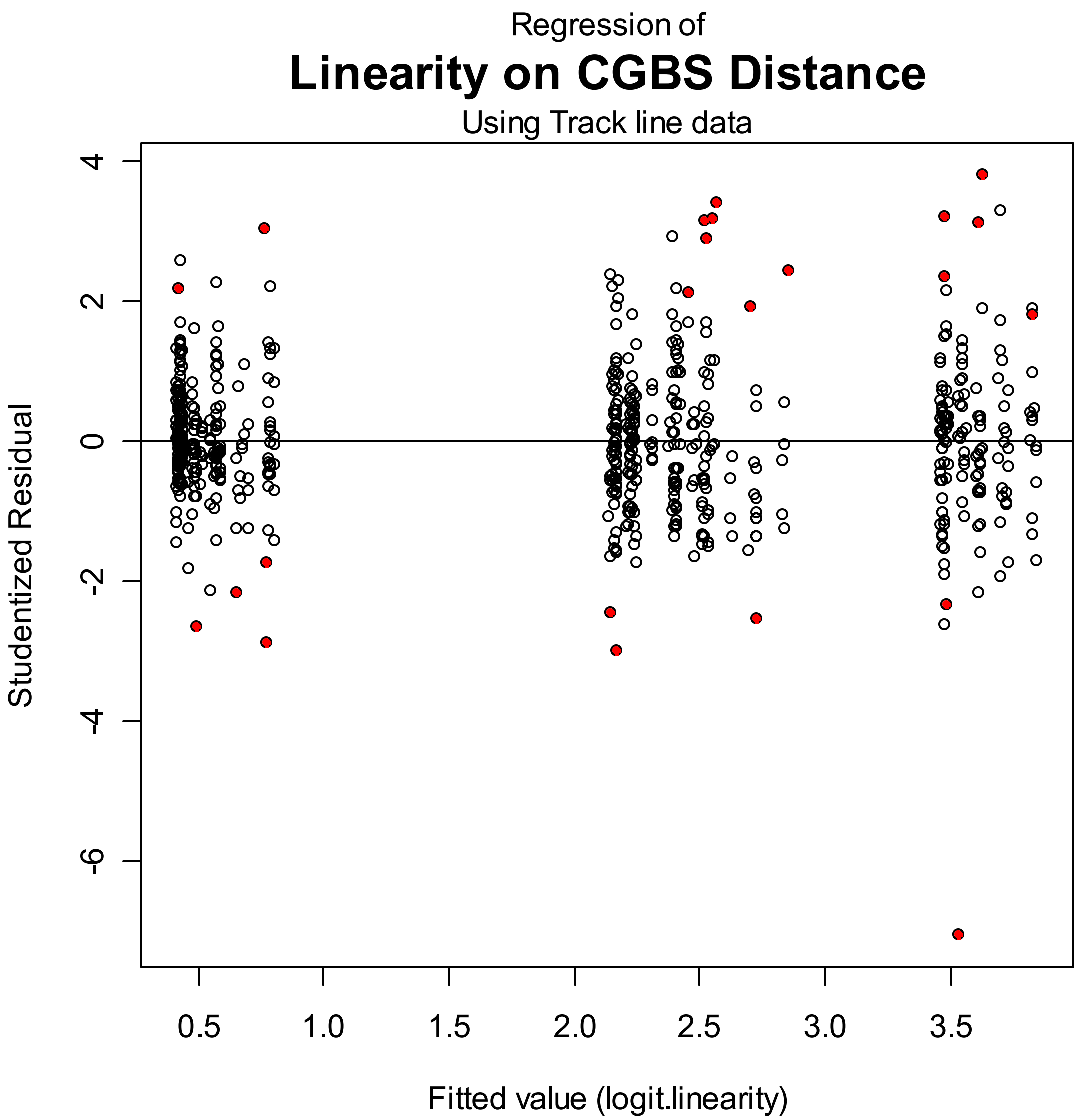

Regression of
Ranging index on CGBS Distance
Using Track line data
Studentized Residual
4
2
0
-2
-4
2.5
3.0
3.5
Fitted value (log.range)

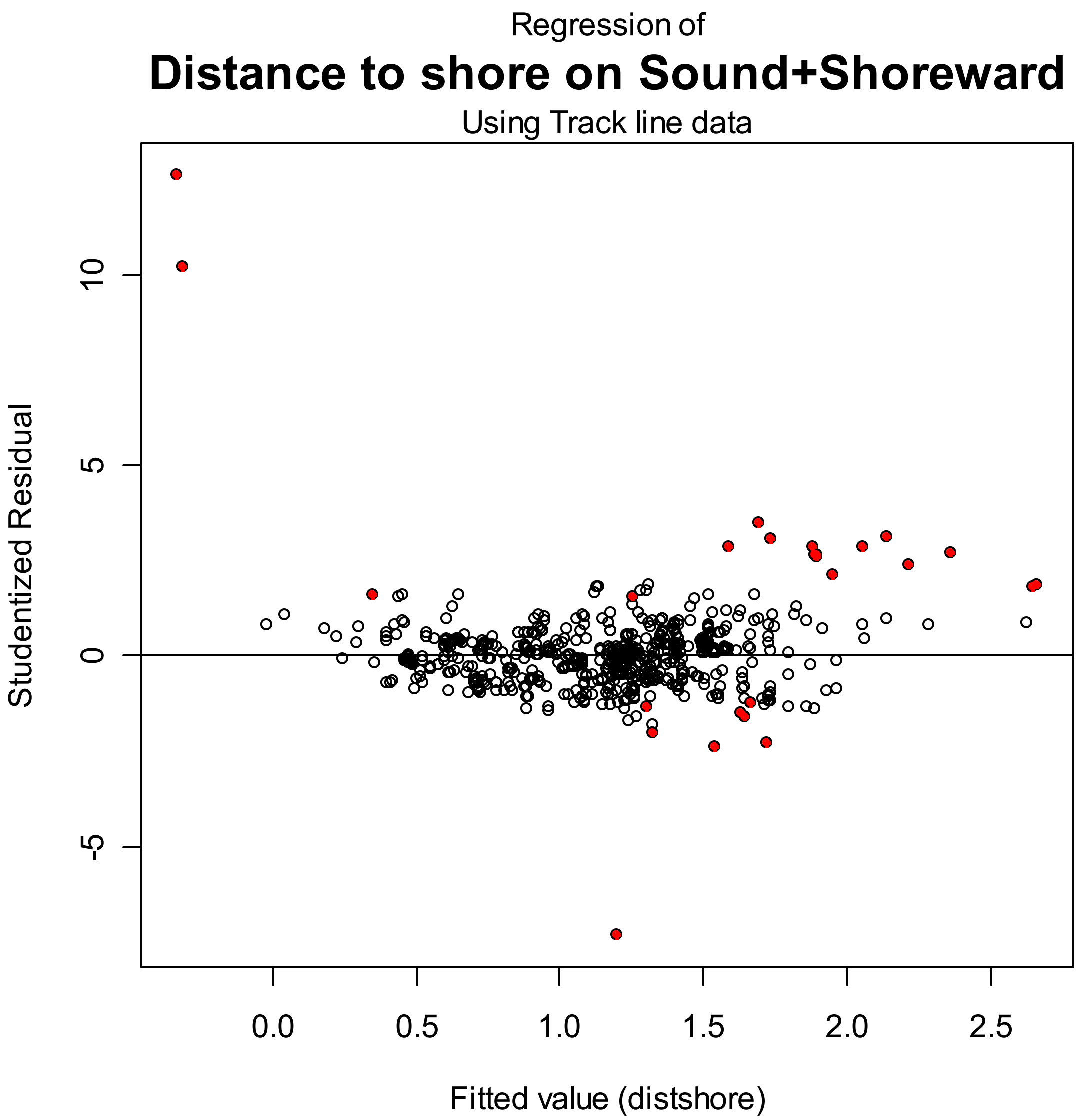

Regression of
Linearity on Sound+Shoreward
Using Track line data
Studentized Residual
Fitted value (logit.linearity)
4
2
0
-2
-4
-6
0
1
2
3
4

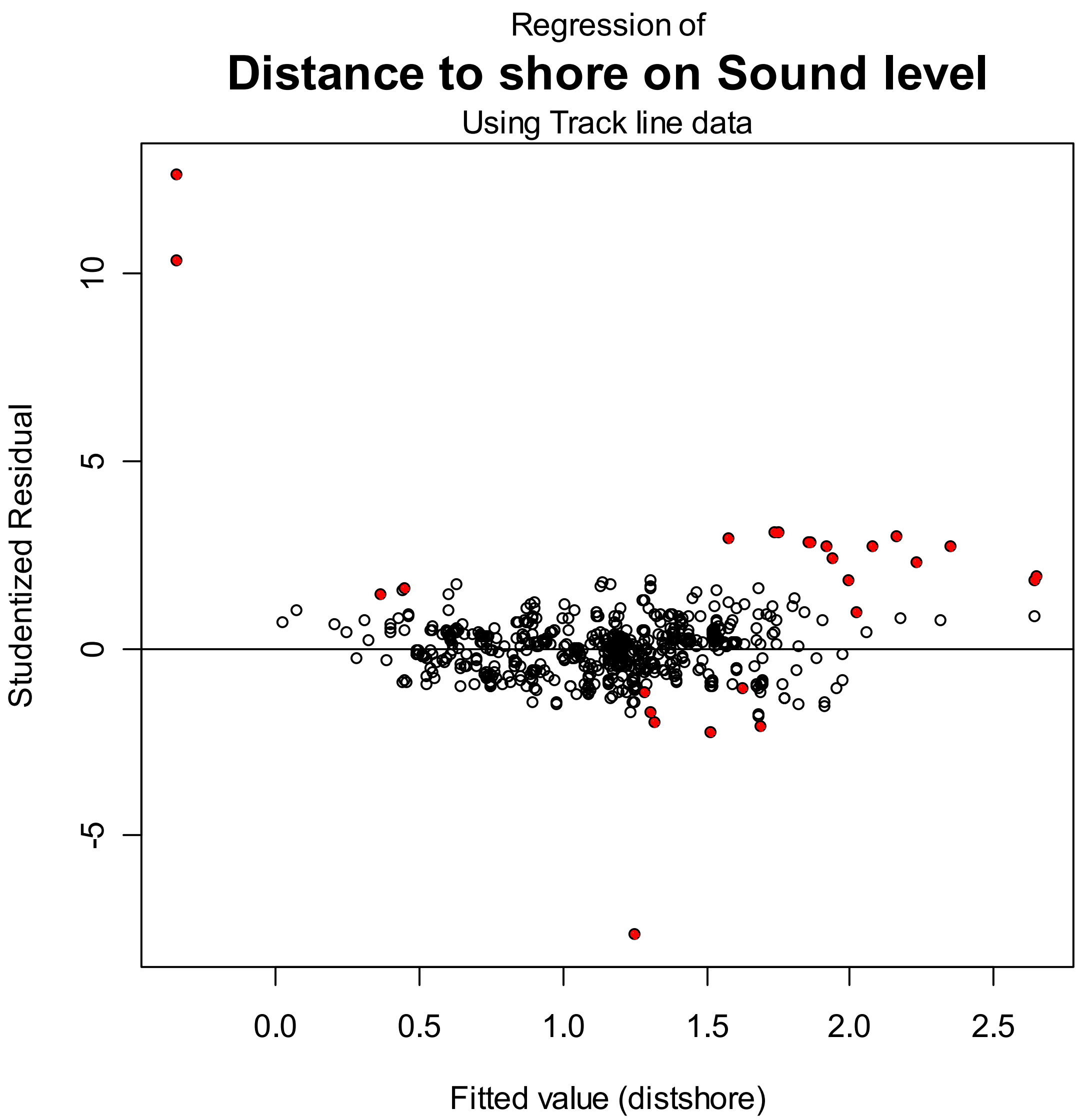

Regression of
Linearity on Sound level
Using Track line data
Studentized Residual
Fitted value (logit.linearity)
4
2
0
-2
-4
-6
0
1
2
3
4

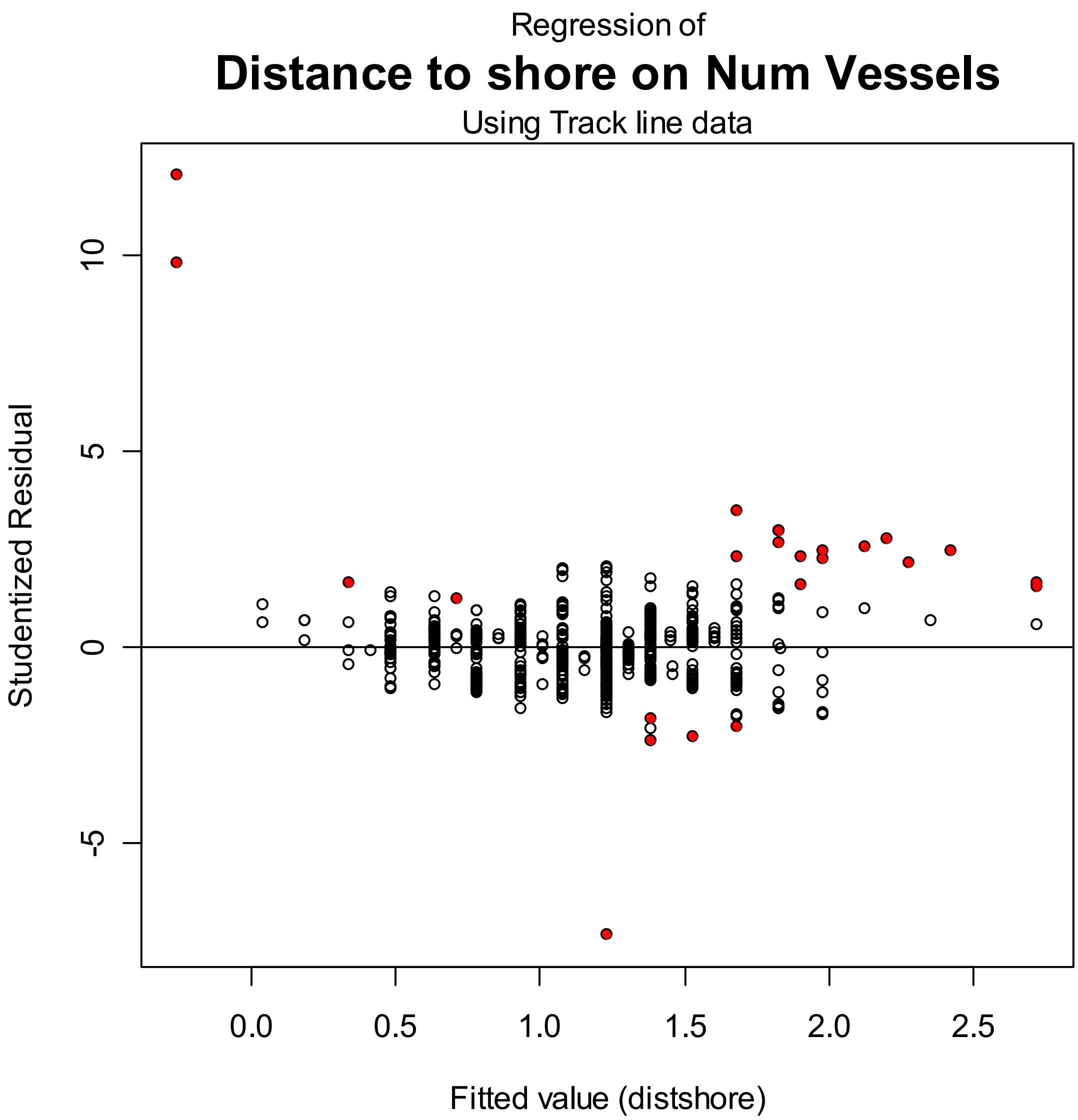

Regression of
Linearity on Num Vessels
Using Track line data
Studentized Residual
4
2
0
-2
-4
-6
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Fitted value (logit.linearity)

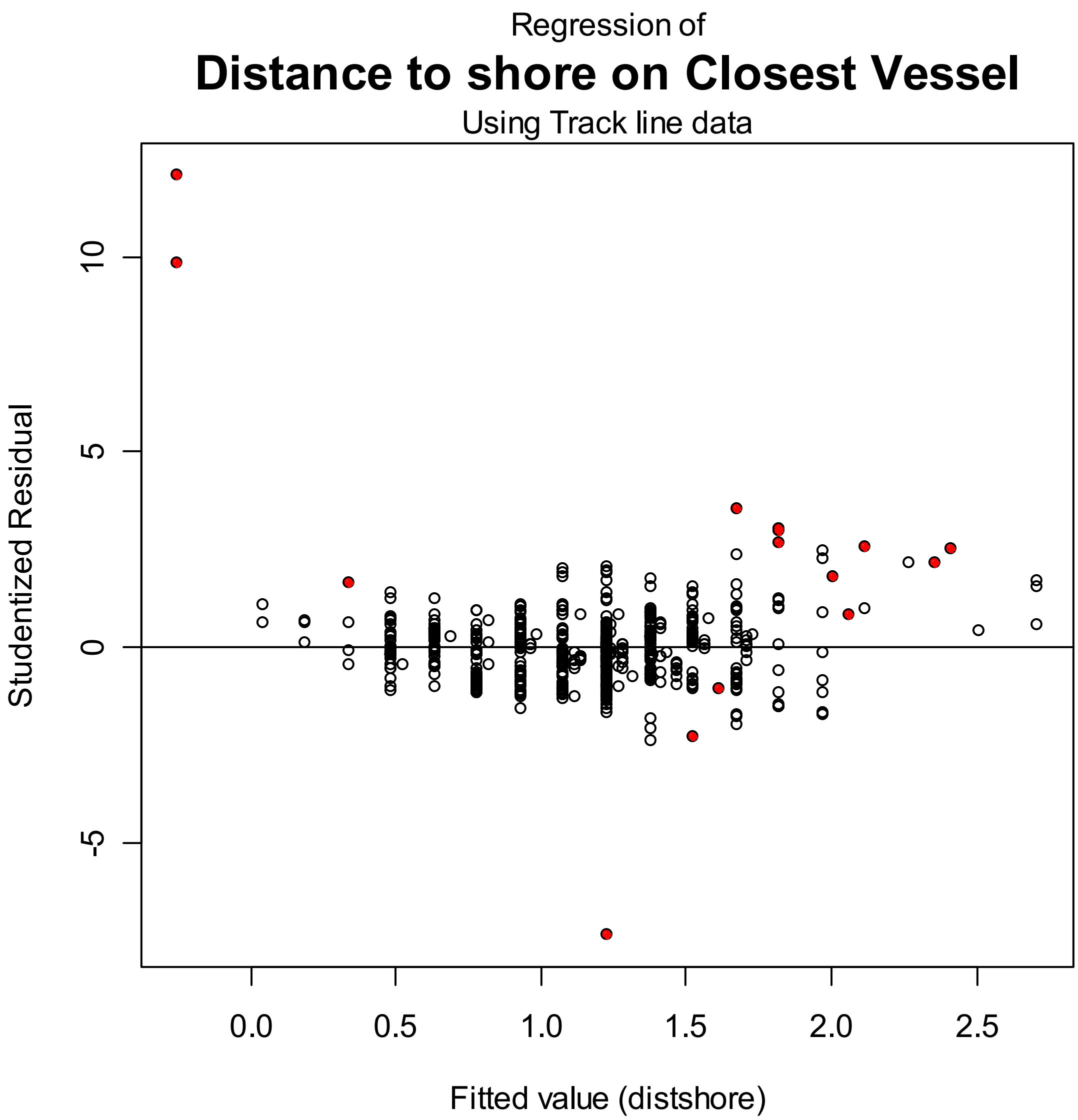

Regression of
Linearity on Closest Vessel
Using Track line data
Studentized Residual
Fitted value (logit.linearity)
4
2
0
-2
-4
-6
0
1
2
3
4

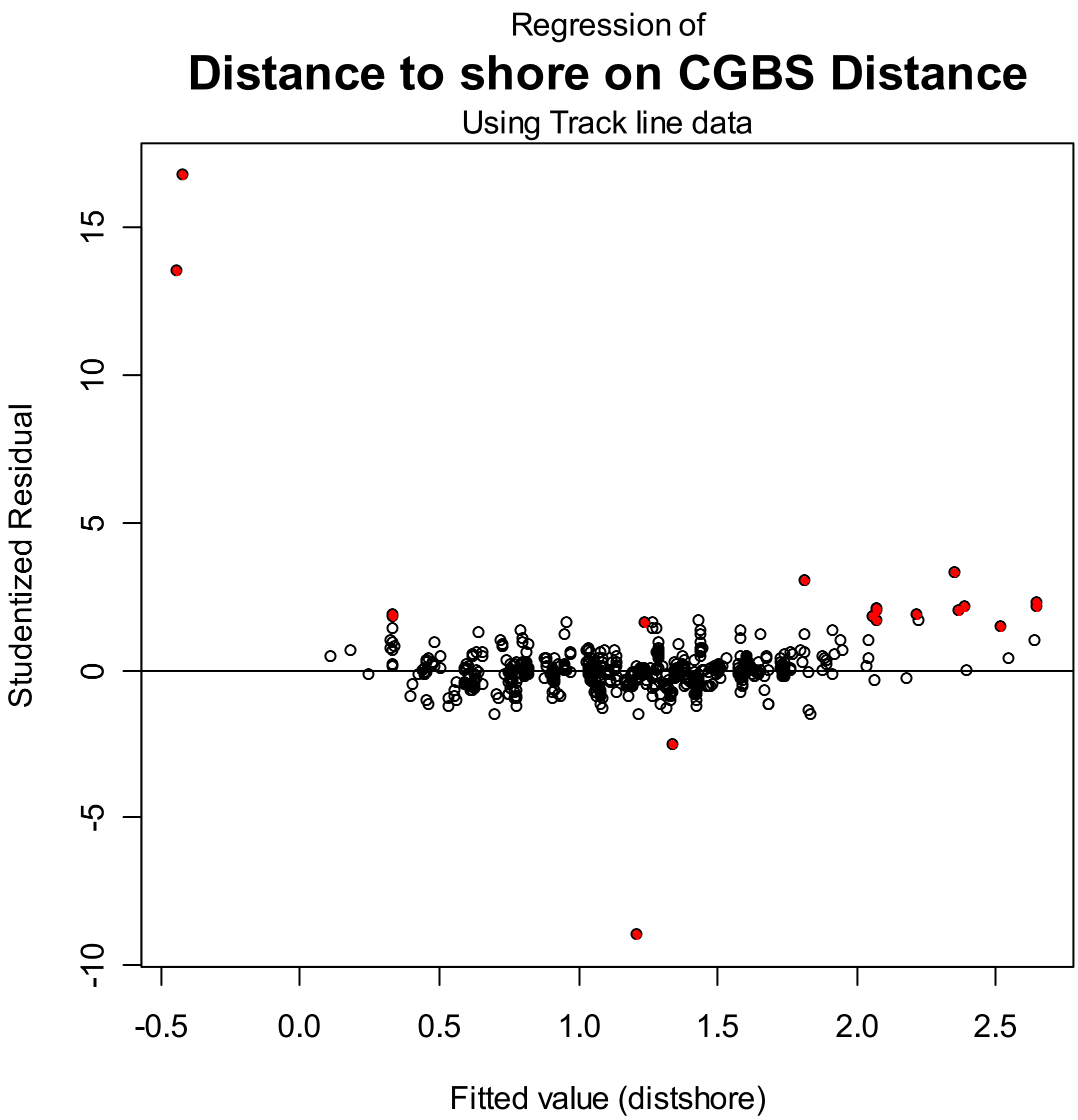

Regression of
Linearity on CGBS Distance
Using Track line data
Studentized Residual
4
2
0
-2
-4
-6
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Fitted value (logit.linearity)

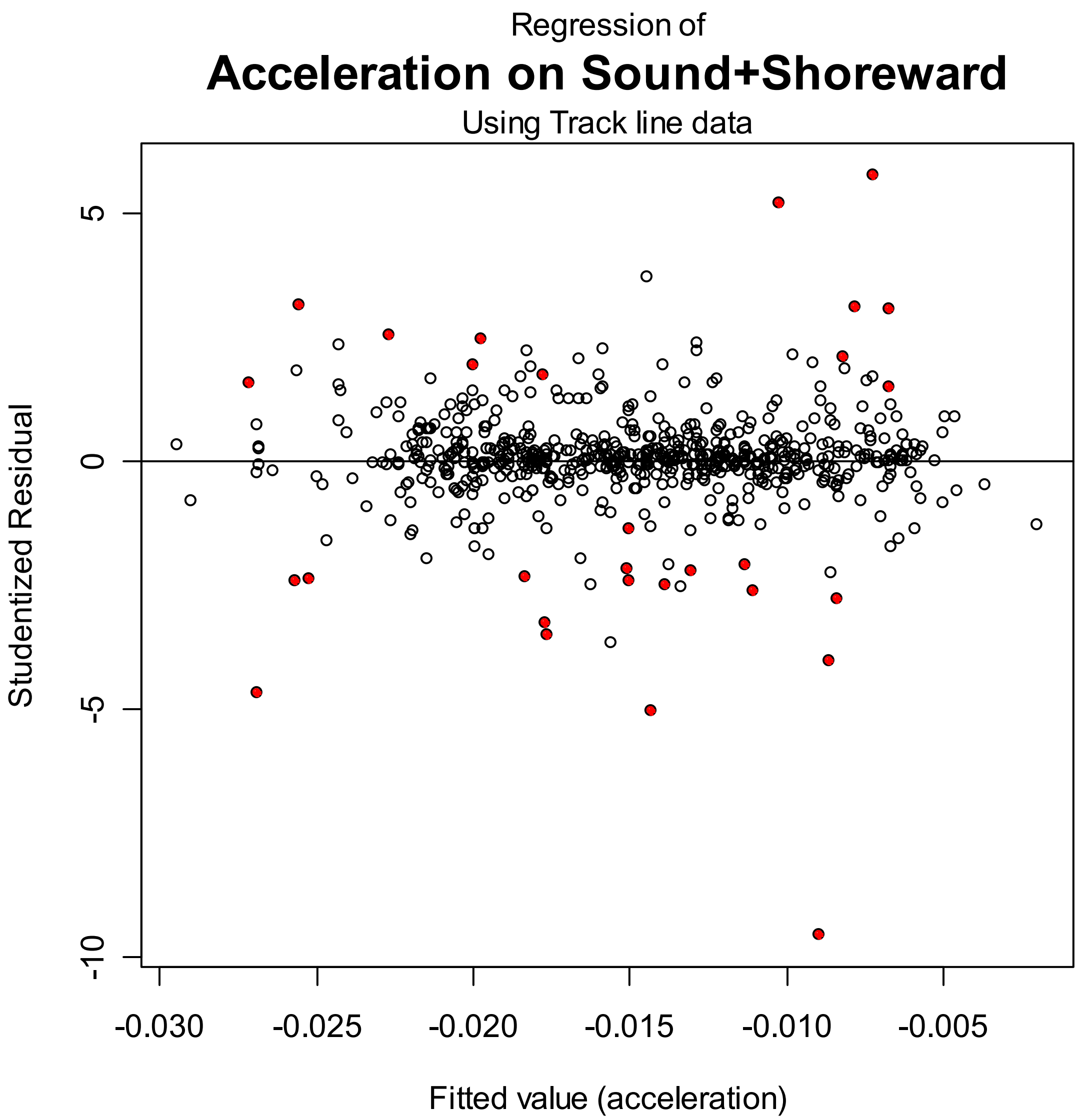

Regression of
Distance to shore on Sound+Shoreward
Using Track line data
Studentized Residual
-5
0
5
10
0.0
0.5
1.0
1.5
2.0
2.5
Fitted value (distshore)

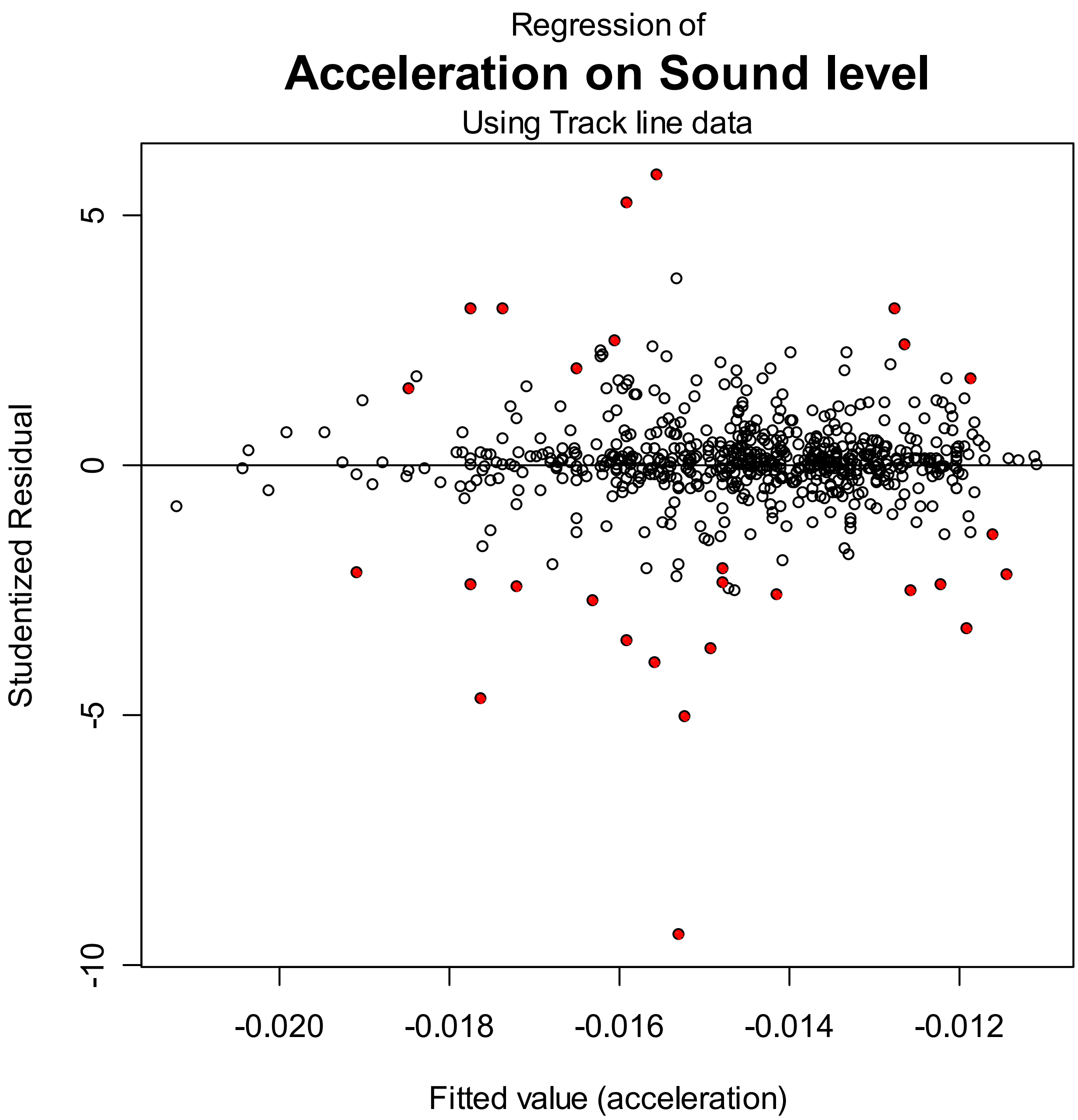

Regression of
Distance to shore on Sound level
Using Track line data
Studentized Residual
10
5
0
-5
0.0
0.5
1.0
1.5
2.0
2.5
Fitted value (distshore)

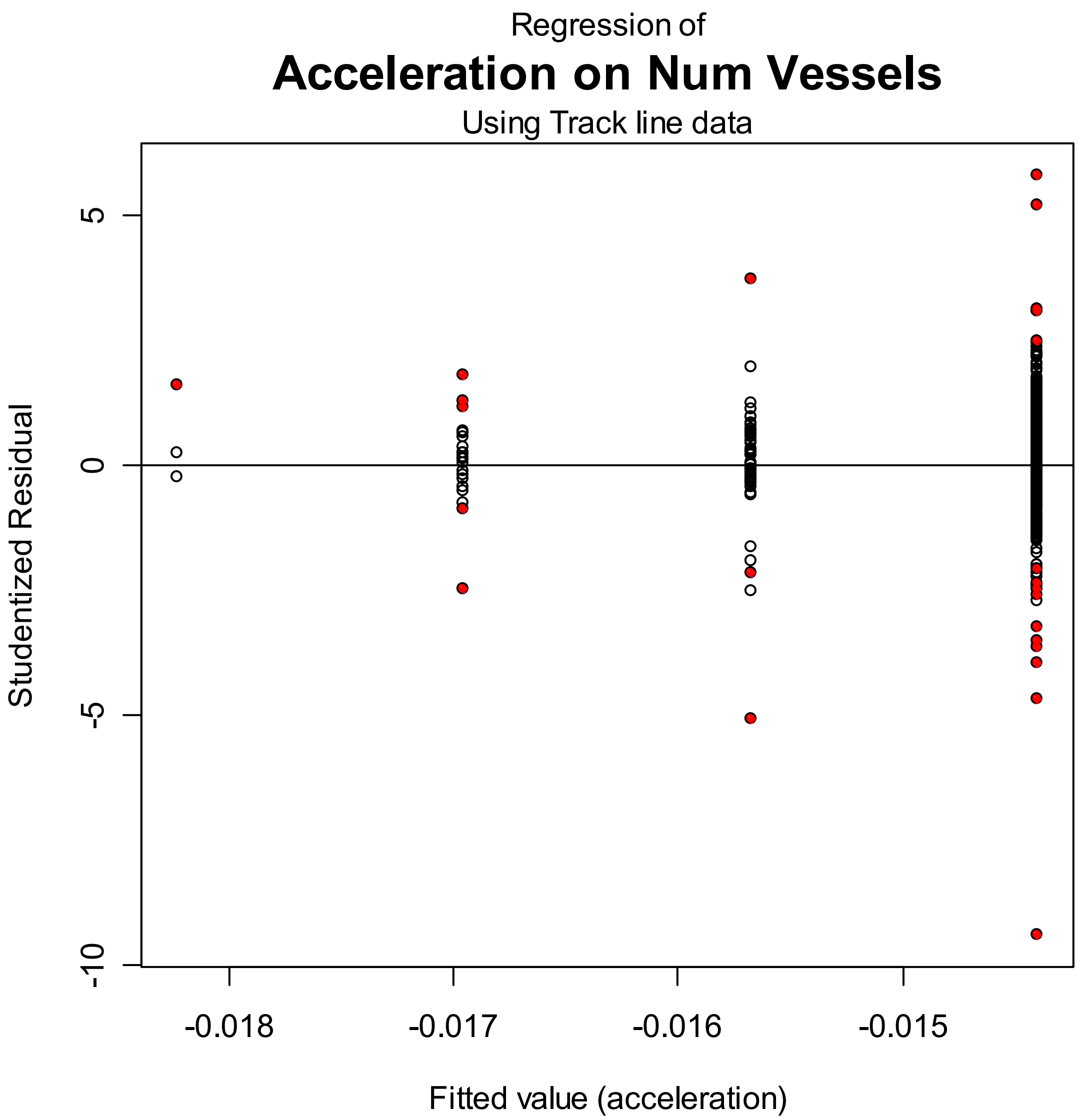

Regression of
Distance to shore on Num Vessels
Using Track line data
Studentized Residual
Fitted value (distshore)
10
5
0
-5
0.0
0.5
1.0
1.5
2.0
2.5

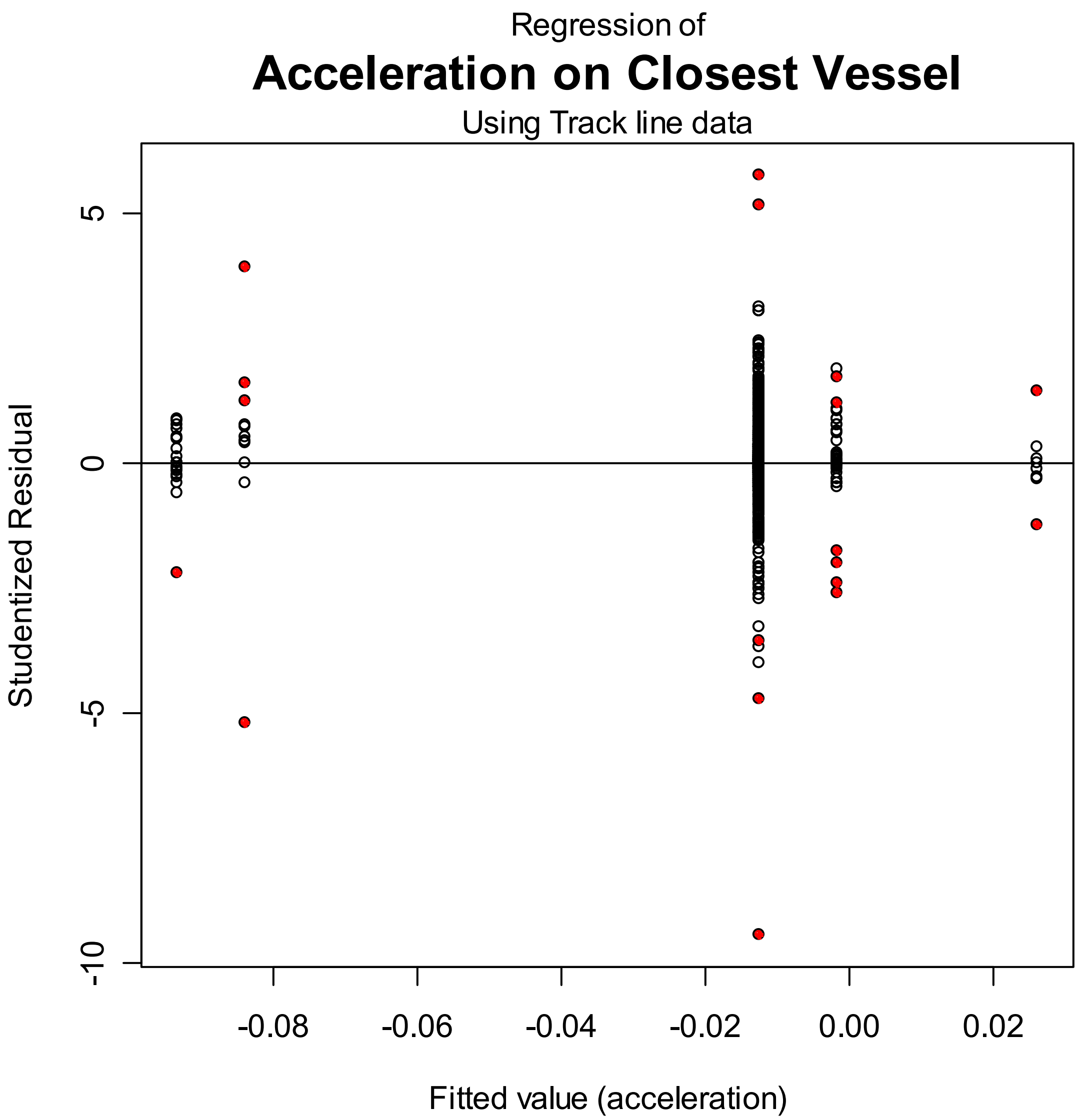

Regression of
Distance to shore on Closest Vessel
Using Track line data
Studentized Residual
-5
0
5
10
0.0
0.5
1.0
1.5
2.0
2.5
Fitted value (distshore)

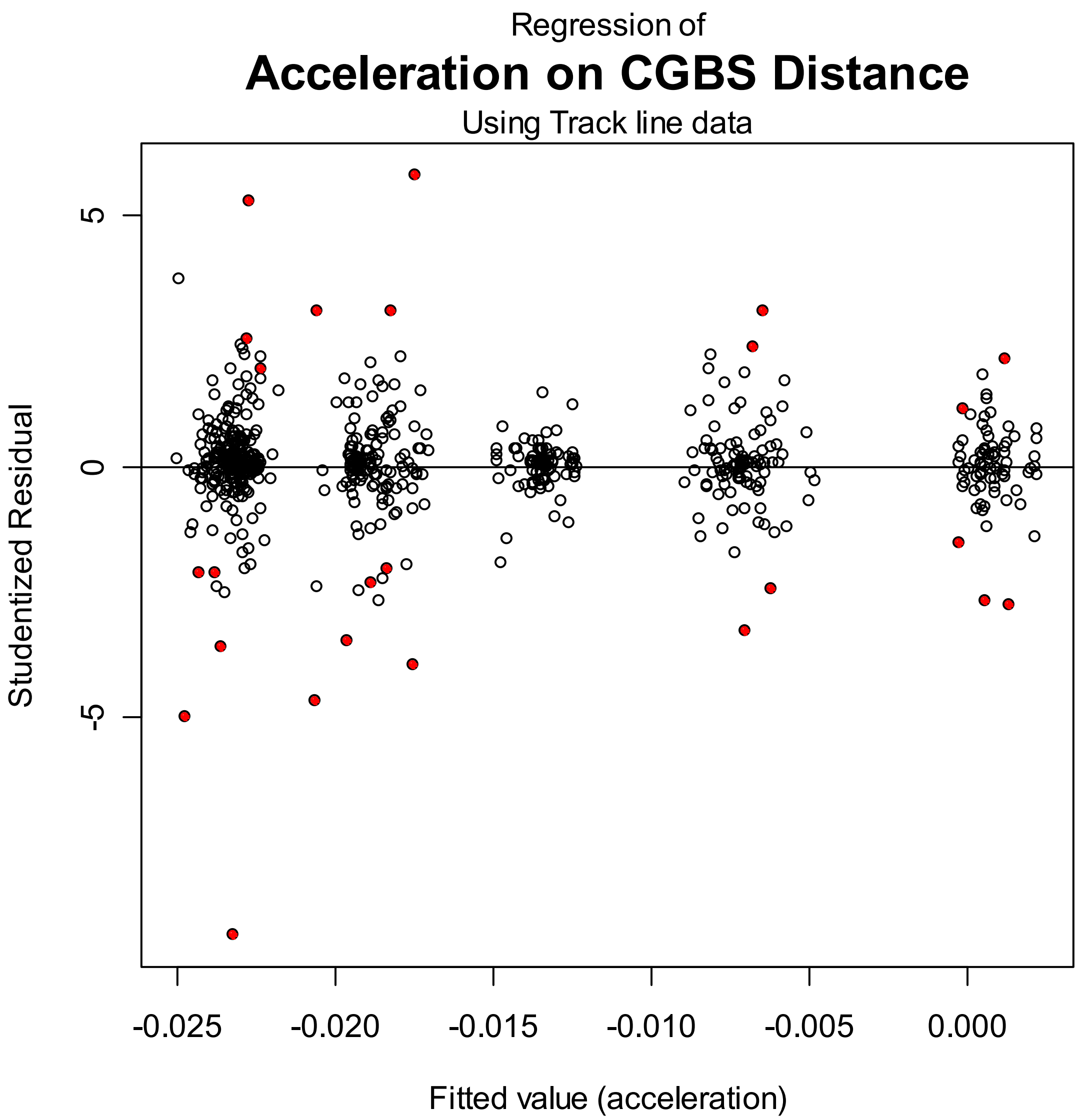

Regression of
Distance to shore on CGBS Distance
Using Track line data
Studentized Residual
15
10
5
0
-5
-10
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
Fitted value (distshore)

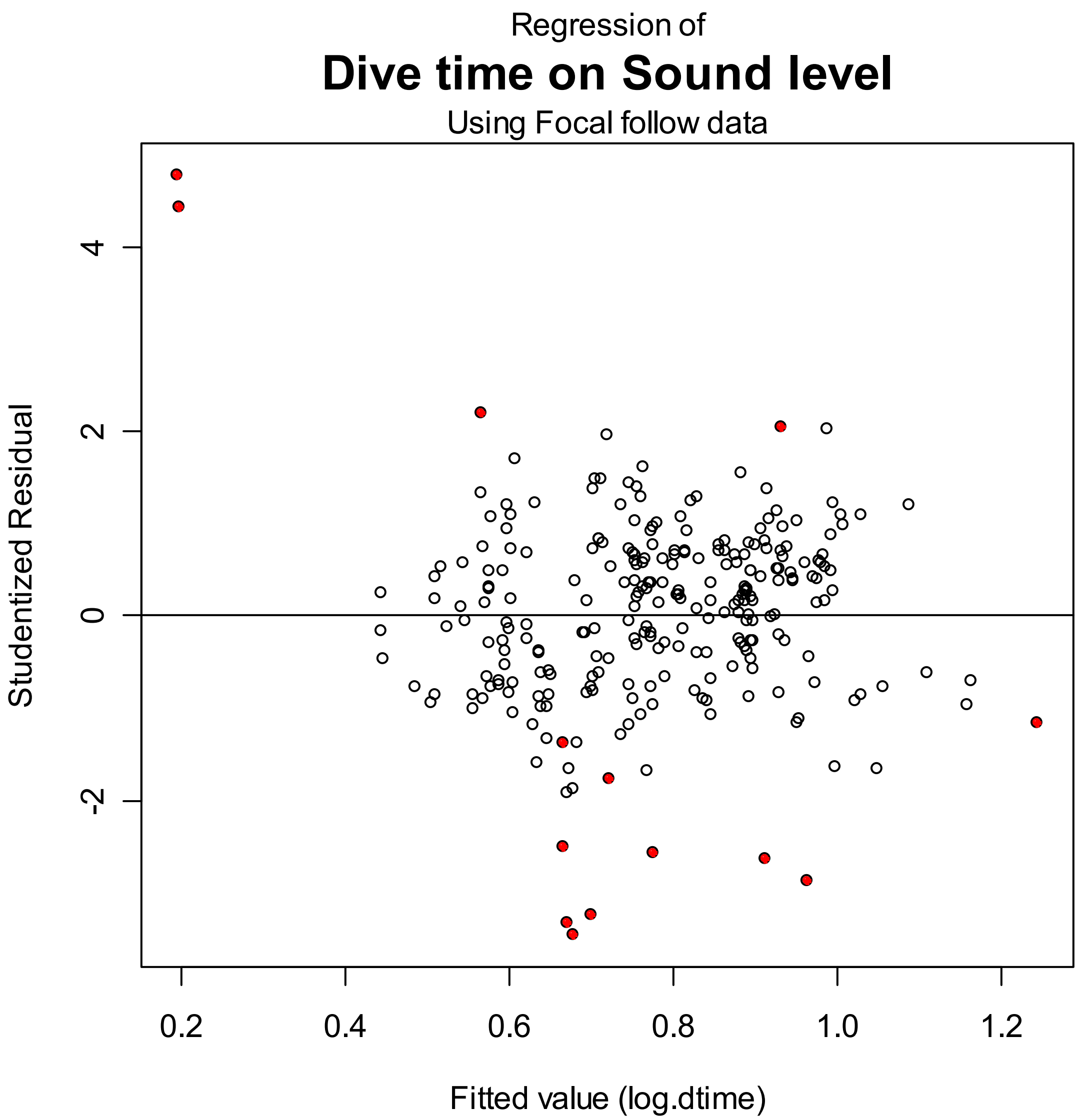

Regression of
Acceleration on Sound+Shoreward
Using Track line data
Studentized Residual
5
0
-5
-10
-0.030
-0.025
-0.020
-0.015
-0.010
-0.005
Fitted value (acceleration)

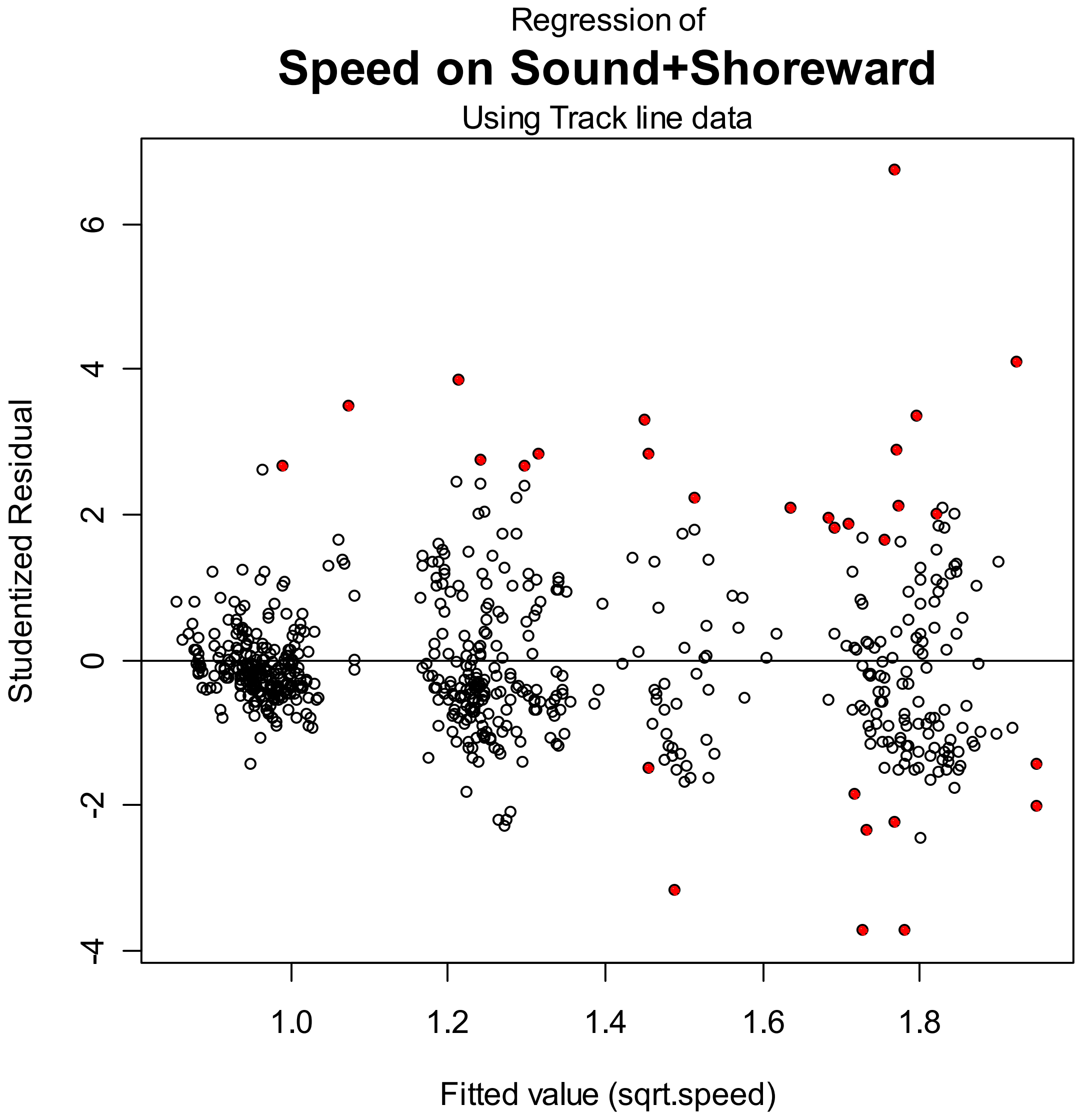

Regression of
Acceleration on Sound level
Using Track line data
Studentized Residual
5
0
-5
-10
-0.020
-0.018
-0.016
-0.014
-0.012
Fitted value (acceleration)

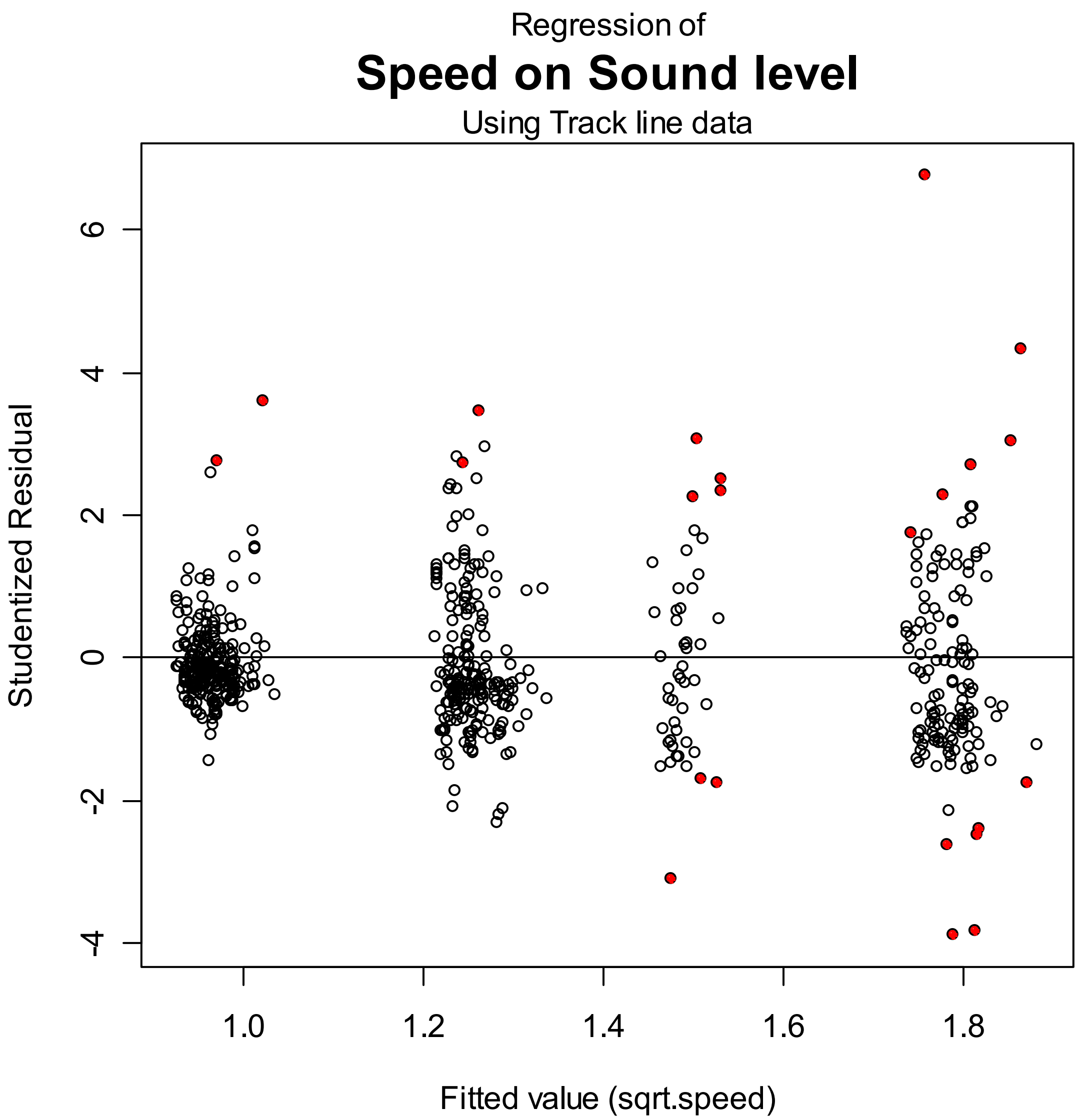

Regression of
Acceleration on Num Vessels
Using Track line data
Studentized Residual
5
0
-5
-10
-0.018
-0.017
-0.016
-0.015
Fitted value (acceleration)

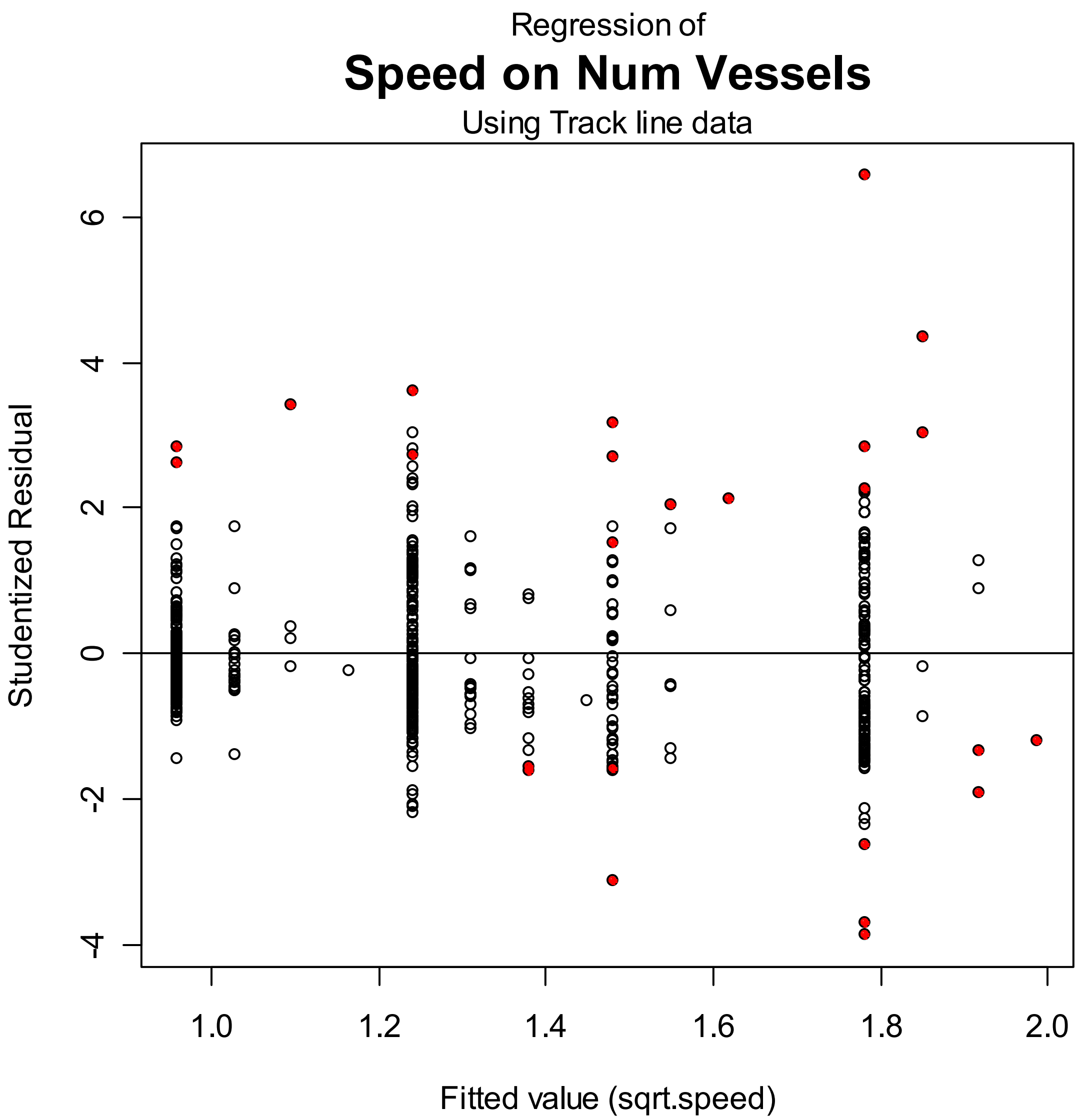

Regression of
Acceleration on Closest Vessel
Using Track line data
Studentized Residual
5
0
-5
-10
-0.08
-0.06
-0.04
-0.02
0.00
0.02
Fitted value (acceleration)


Regression of
Acceleration on CGBS Distance
Using Track line data
Studentized Residual
Fitted value (acceleration)
5
0
-5
-0.025
-0.020
-0.015
-0.010
-0.005
0.000


Regression of
Dive time on Sound level
Using Focal follow data
Studentized Residual
Fitted value (log.dtime)
4
2
0
-2
0.2
0.4
0.6
0.8
1.0
1.2


Regression of
Speed on Sound+Shoreward
Using Track line data
Studentized Residual
Fitted value (sqrt.speed)
-4
-2
0
2
4
6
1.0
1.2
1.4
1.6
1.8


Regression of
Speed on Sound level
Using Track line data
Studentized Residual
6
4
2
0
-2
-4
1.0
1.2
1.4
1.6
1.8
Fitted value (sqrt.speed)


Regression of
Speed on Num Vessels
Using Track line data
Studentized Residual
Fitted value (sqrt.speed)
-4
-2
0
2
4
6
1.0
1.2
1.4
1.6
1.8
2.0

Appendix C: Preliminary Scan Sampling Analyses

To further investigate the effects of sound in relation to distance from shore observations (see Results), scan data (see Gailey *et al.* 2006) were preliminarily evaluated with available acoustic information from track and focal follow observation data. Scan observations represented 593 gray whale sightings from 13 July to 7 September. A 20-minute threshold difference between the sighting and the available acoustic data was taken and resulted in a total of 331 sightings with overlapping acoustic information from 26 July to 6 September. Nearby (< 5 km) vessel presence was also examined to investigate the potential influence of nearshore research vessels and changes in sound levels due to their presence. These plots highlight two points: 1) research vessels operating within the feeding grounds contribute significantly to the sound exposure budget of the observed whales and 2) there is no clear pattern in relation to observation stations/geographic regions and sound levels. We had anticipated that sound levels would have been higher at the two stations closest to the CGBS construction activity. However, as Figure C.3 and C.4 highlight, some of the highest sound levels were observed at more northern locations then the two stations closest to the CGBS activity (1st Station and South Station).

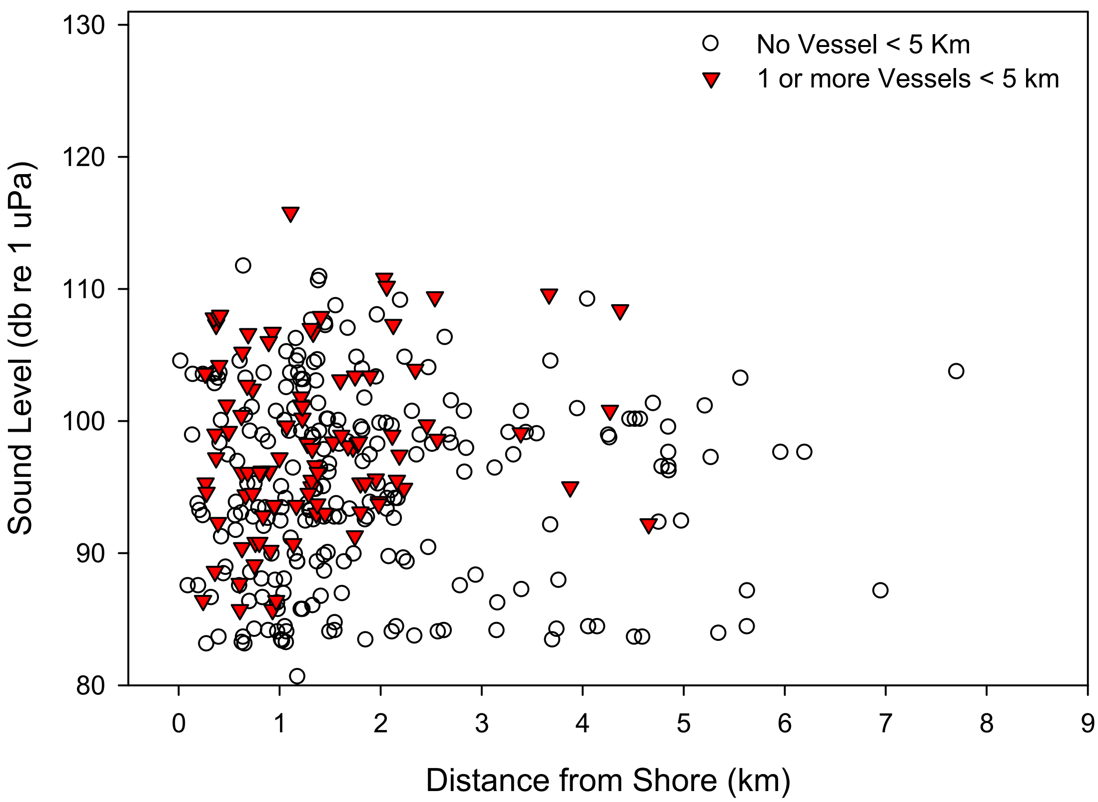


Figure C. 1. Scatter plot of western gray whales distance from shore of western grays in relation to sound levels during scan sampling observations.

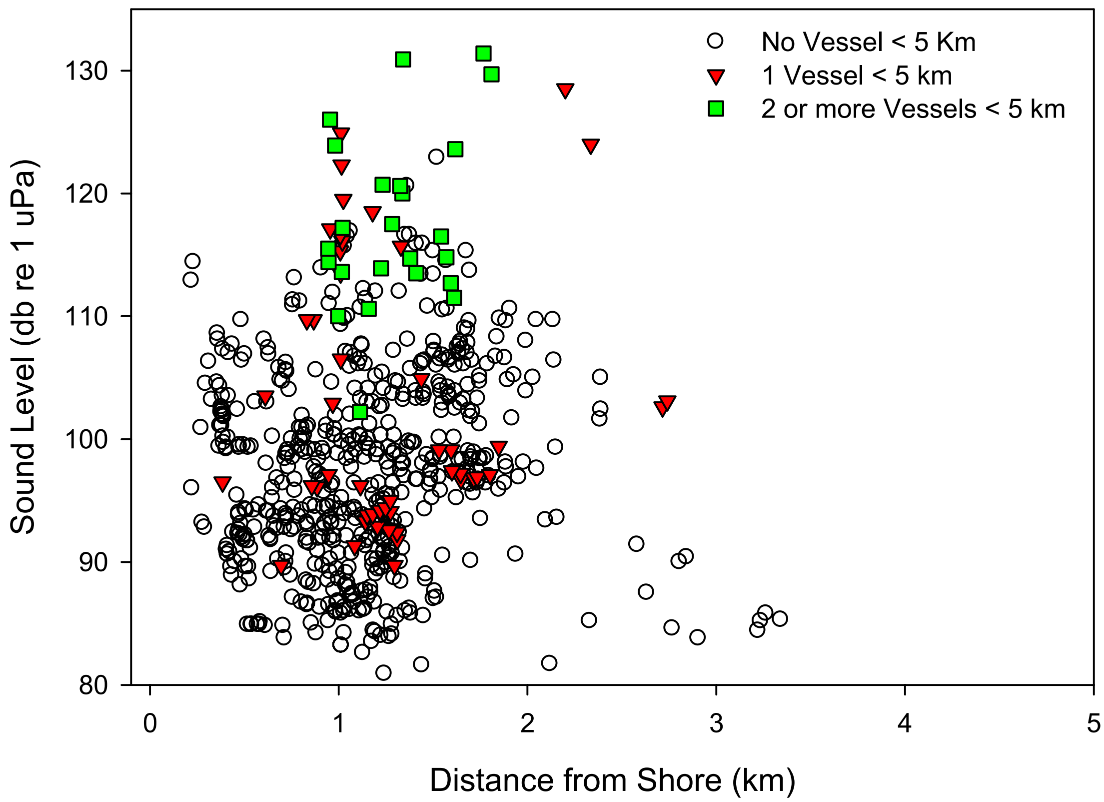


Figure C. 2. Scatter plot of western gray whales distance from shore of western grays in relation to sound levels during theodolite tracking observations.

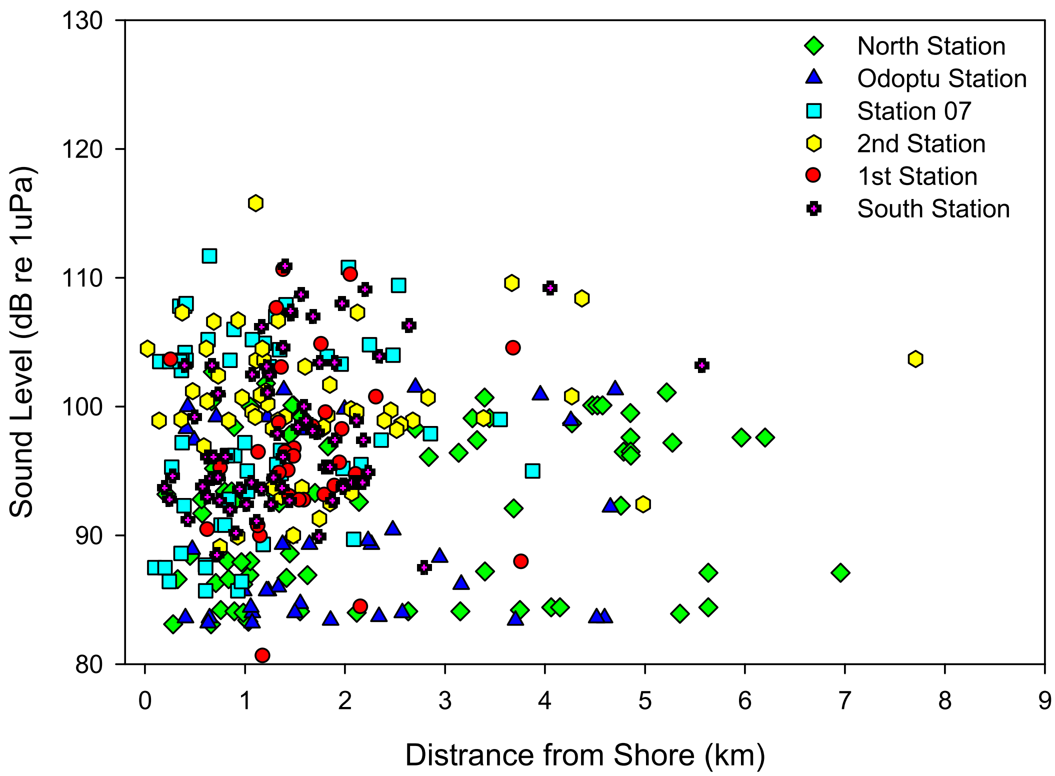


Figure C. 3. Scatter plot of western gray whales distance from shore in relation to exposed sound levels at six geographic locations during scan sampling surveys.

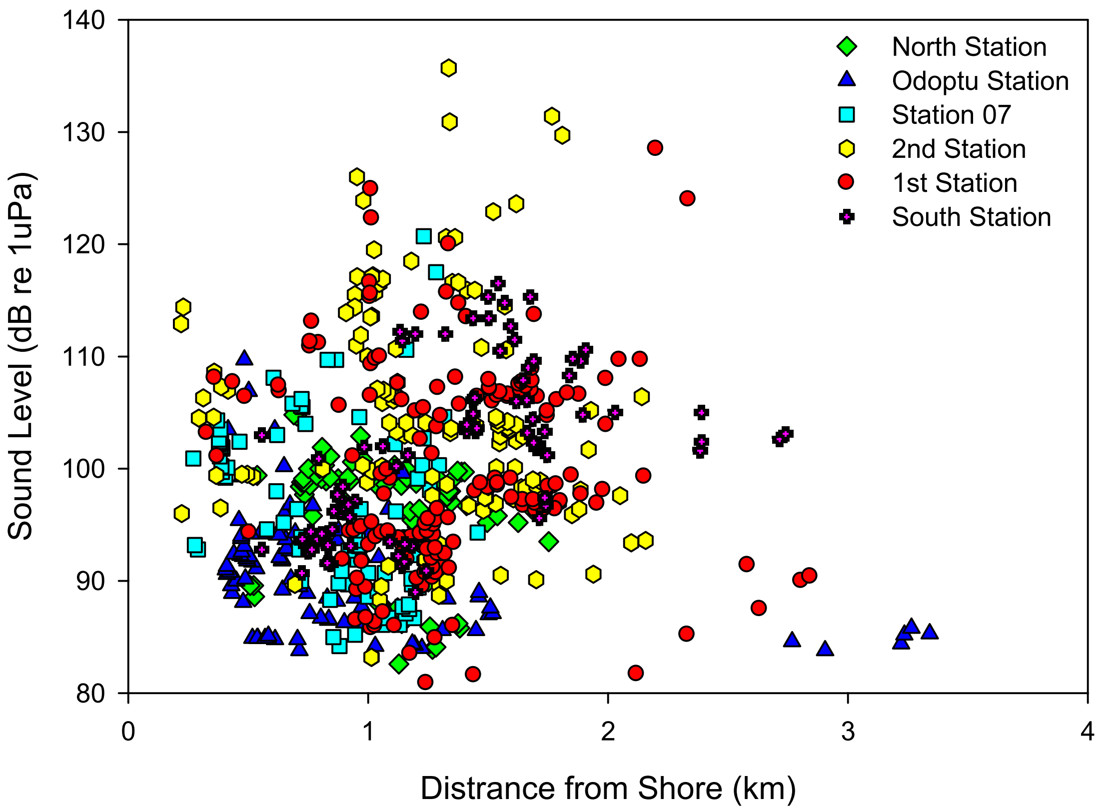


Figure C. 4. Scatter plot of western gray whales distance from shore in relation to exposed sound levels at six geographic locations during theodolite tracking sessions.

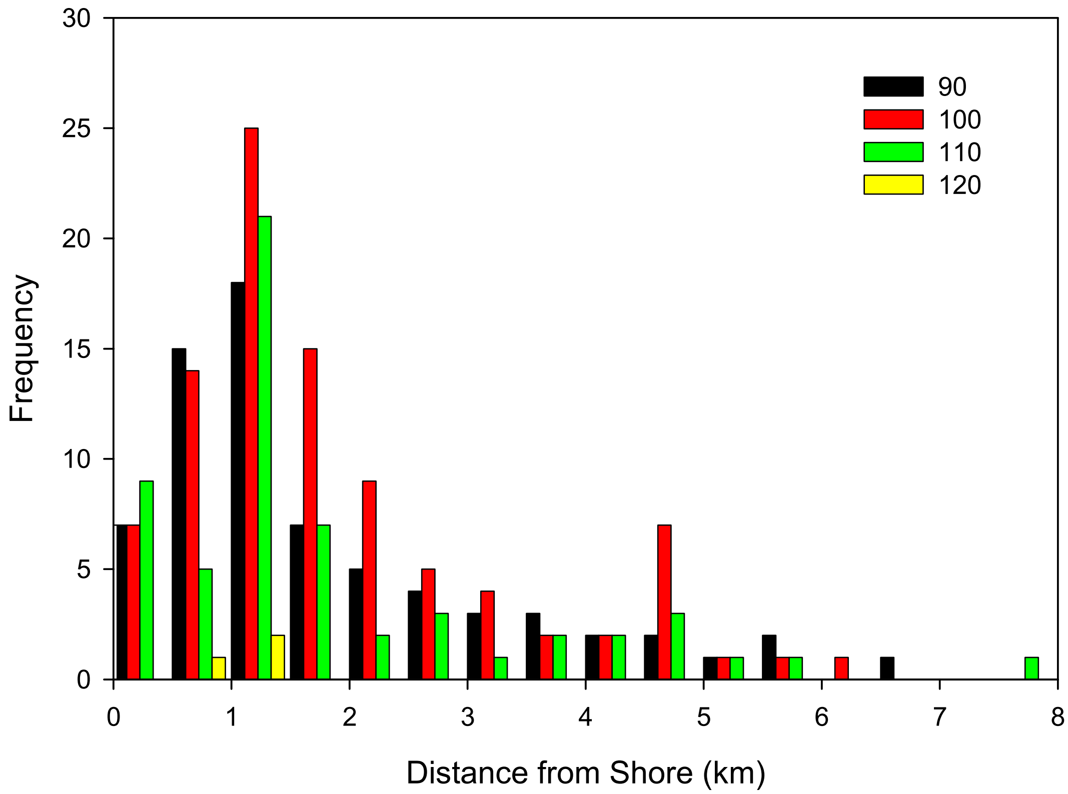


Figure C. 5. Frequency distribution of sound levels (db re 1uPa) and distance from shore of western gray whales during scan sampling surveys when no vessels were observed within 5 km of the whale.

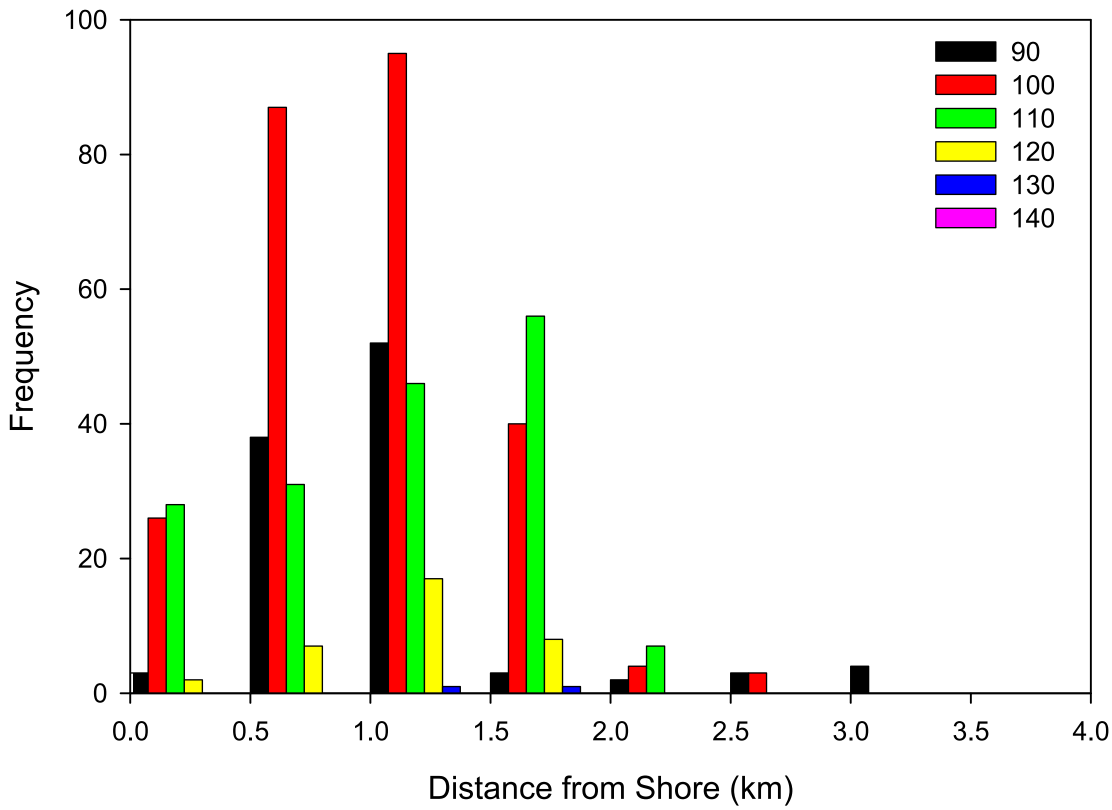


Figure C. 6. Frequency distribution of sound levels (db re 1uPa) and distance from shore of western gray whales during tracking sesssions when no vessels were observed within 5 km of the whale.

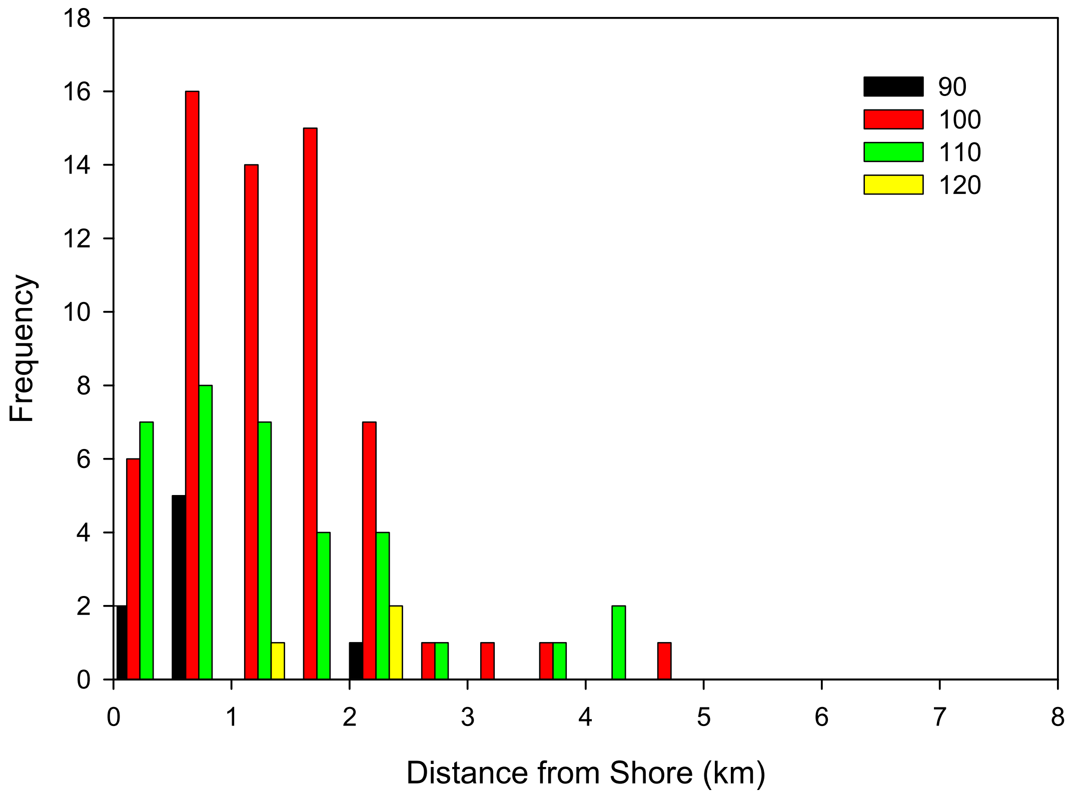


Figure C. 7. Frequency distribution of sound levels (db re 1uPa) and distance from shore of western gray whales during scan sampling surveys when one or more vessels were observed within 5 km of the whale.

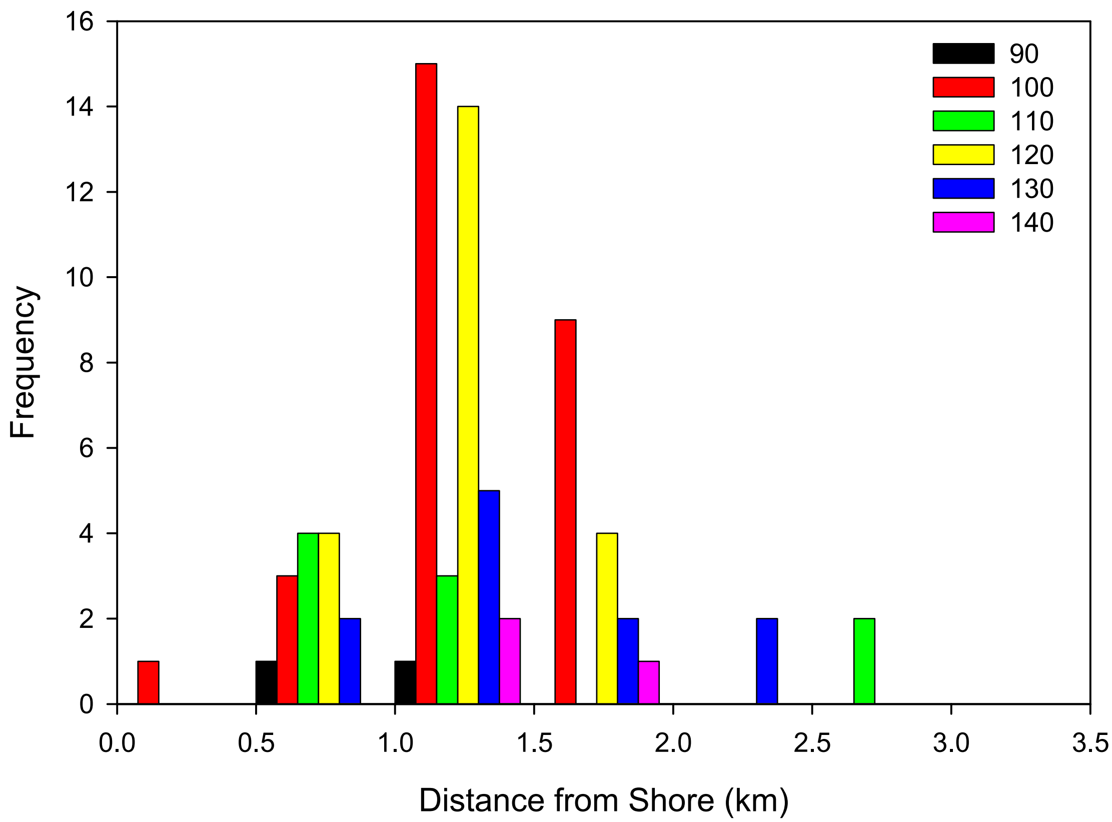


Figure C. 8. Frequency distribution of sound levels (db re 1uPa) and distance from shore of western gray whales during tracking sessions when one or more vessels were observed within 5 km of the whale.